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W. ASKLING, M.E., AND E. ROESLER, M.E.

With 178 Illustrations, including a Folding Plate.



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CHARLES GRIFFIN AND COMPANY LIMITED,  
EXETER STREET, STRAND, W.C. 2.  
1912.

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*Translators:*  
E. ADAMS-RAY AND C. W. ASKLING.



## PREFACE.

THE present work is partly a translation, and partly an adaptation, of the authors' book on the same subject which was published in Swedish in 1909. One condition laid down for the first publication of the book was that the price should be relatively low—a condition which, of course, fixed the limits of the ground to be covered by the work. A book based on theoretical foundations must have had those limits considerably wider, for if ever theory, design, and the possibilities of practical execution should be viewed simultaneously and in the same light, it is in the case of the industry in question. Such a book, then, would have become too voluminous, and have been altogether too expensive. On the other hand, a purely descriptive work would have become merely a mass of facts, without any real connecting link. The authors, therefore, have tried to hold a middle course and, while pointing out the essential, fundamental points of view, have given a survey of the industry dealt with.

In the present English edition this plan has been retained, but considerable additions and alterations have been made.

The work has been divided between the two authors. E. Roestler has written the first part of the book, *i.e.* that treating of producers, etc., while C. W. Askling has carried out the second part, which deals with the engines, etc.

One of the differences between the English and the Swedish editions is that the present work has, so to say, been made more international. The authors have kept in view the efforts made in modern techniques to employ cheap fuels for power purposes, and, also, the endeavours made to utilise for marine purposes the great advantages offered by combustion engines. Want of space has made it necessary to omit an historical survey of the development of the combustion engine, in spite of the subject being a most instructive one. The British system of weights and measures has been used

throughout, but data have often been given in the metric system too, as the latter is now being used to a great extent in the English-speaking world, e.g. in the entire English motor-car industry.

We here beg to express our warmest thanks to the various manufacturers and firms in different parts of the globe who have so very willingly placed drawings at our disposal. In this connection we beg to point out very earnestly that the order in which the different firms have been mentioned was determined merely by a regard for suitability and convenience, and we also wish to state that the omission of the name of any firm by no means implies any want of appreciation of its merits.

Finally, it is with extreme pleasure that we offer our warmest thanks to Mr. E. Adams-Réy for the careful and untiring energy with which he has carried out the translation of the greater part of the book.

THE AUTHORS.

BERNIESEN AND STOCKHOLM, SWEDEN.  
November 1911.

## CONTENTS.

### PART I.

#### CHAPTER I.

|  |           |
|--|-----------|
| THE METHOD OF WORKING OF INTERNAL COMBUSTION<br>ENGINES COMPARED WITH THAT OF OTHER HEAT-<br>ENGINES . . . . . | PAGE<br>I |
|--|-----------|

#### CHAPTER II.

|   |   |
|---|---|
| THE PRODUCTION, PREPARATION, COMPOSITION, AND<br>QUALITIES OF THE FUELS MOSTLY EMPLOYED IN<br>GAS- OR OIL-ENGINES . . . . . | 3 |
|---|---|

##### I. GASEOUS FUELS :—

|   |    |
|---|----|
| (a) Illuminating Gas . . . . .  | 6  |
| (b) Producer-Gas . . . . .  | 7  |
| The Production of Producer-Gas from Fuels poor in<br>Hydrocarbons . . . . . | 21 |
| The Production of Producer-Gas from Fuels rich in<br>Hydrocarbons . . . . . | 23 |
| (c) Natural Gas . . . . .   | 40 |
| (d) Blast-Furnace Gas . . . . .   | 40 |
| (e) Coke-Oven Gas . . . . .   | 56 |

##### II. LIQUID FUELS :—

|   |    |
|---|----|
| General Qualities . . . . .   | 57 |
| The Physical and Chemical Qualities of Liquid Fuels as<br>Characteristics of their Capability of being employed<br>for Combustion Engines . . . . . | 57 |
| Various Kinds of Liquid Fuel . . . . .  | 61 |
| (a) Distillates of Crude Petroleum . . . . .  | 61 |
| (b) Alcohol . . . . .   | 63 |
| (c) Distillates of Lignite . . . . .  | 64 |
| (d) Coal- and Shale-oils . . . . .  | 65 |

viii INTERNAL COMBUSTION ENGINES AND GAS-PRODUCERS.

CHAPTER III.

PRODUCERS WITH ACCESSORIES: GENERAL PRINCIPLES  
OF DESIGN.

|  | PAGE |
|--|------|
| (a) THE PRODUCER                             | 66   |
| (b) THE VAPORISER                            | 70   |
| (c) CLEANING AND DRYING APPARATUS AND PIPING | 76   |

CHAPTER IV.

GENERAL RULES FOR THE CARE OF SUCTION-GAS  
PLANTS

82

CHAPTER V.

PRODUCER PLANTS BUILT FOR GAS-POWER PURPOSES.

|  |    |
|--|----|
| I. PRODUCER PLANTS FOR FUELS POOR IN HYDROCARBONS,<br>SUCH AS ANTHRACITE, COKE, ETC. | 86 |
| II. PRODUCER PLANTS FOR BITUMINOUS FUELS, SUCH AS PEAT,<br>LIGNITE, COAL, ETC.       | 93 |

PART II.

CHAPTER I

INTRODUCTION

101

PRINCIPAL POWER-CYCLES OF INTERNAL COMBUSTION  
ENGINES.

|                      |     |
|----------------------|-----|
| I. EXPLOSION ENGINES | 103 |
| PETROL ENGINES       | 108 |

CONTENTS.

CHAPTER II.

GAS-ENGINES.

|   | PAGE |
|---|------|
| I. GENERAL DESCRIPTION  | 103  |
| II. THE VARIOUS PARTS OF THE ENGINE :—                                  |      |
| The Engine-Bed and the Cylinder   | 112  |
| Power-Transmitting Parts  | 116  |
| The Valves  | 117  |
| Ignition Systems  | 121  |
| Starting Arrangements   | 142  |
| Cooling   | 146  |
| Piping, Silencers, etc.   | 150  |
| Lubrication   | 155  |
| Foundations   | 159  |
| III. DIFFERENT SYSTEMS OF GOVERNING                                     | 159  |
| IV. DIFFERENT TYPES OF ENGINES :—                                       |      |
| Smaller Engines   | 165  |
| Large Engines   | 173  |
| Four-Stroke Engines   | 175  |
| Two-Stroke Engines  | 191  |
| Some Points of Comparison between Four-Stroke and<br>Two-Stroke Engines | 194  |
| Suction-Gas Engines for Ships   | 198  |

CHAPTER III.

OIL-ENGINES.

|   |     |
|---|-----|
| I. ACCESSORIES :—                                 |     |
| Carburetters                                      | 203 |
| Vaporisers  | 209 |
| Oil-Pumps   | 211 |
| II. DIFFERENT TYPES OF OIL-ENGINES :—             |     |
| Stationary and Marine Engines                     | 213 |
| Reversible Engines                                | 222 |
| Engines reversible by means of Premature Ignition | 222 |
| Engines reversible by means of Compressed Air     | 230 |
| Automobile Motors                                 | 243 |
| Water-cooled Motors                               | 245 |
| Air-cooled Motors                                 | 249 |
| Flying-machine Motors                             | 252 |
| The Humphrey Gas-Pump                             | 257 |

INTERNAL COMBUSTION ENGINES AND GAS-PRODUCERS.

CHAPTER IV.

|   | PAGE |
|---|------|
| ON COMBUSTION . . . . .                             | 261  |
| HEAT-BALANCE OF COMBUSTION ENGINES . . . . .        | 269  |
| CALCULATION OF THE CYLINDER-DIMENSIONS . . . . .    | 270  |
| DISRUPTIONS IN THE WORKING . . . . .                | 280  |
| MEASURES OF PRECAUTION . . . . .                    | 283  |
| THE WORKING ECONOMY OF COMBUSTION ENGINES . . . . . | 283  |

CHAPTER V.

|                              |     |
|------------------------------|-----|
| SOME INSTALLATIONS . . . . . | 288 |
| REDUCTION-FACTORS . . . . .  | 299 |
| INDEX . . . . .              | 301 |

# INTERNAL COMBUSTION ENGINES AND GAS-PRODUCERS.

## PART I.

### CHAPTER I.

#### THE METHOD OF WORKING OF INTERNAL COMBUSTION ENGINES COMPARED WITH THAT OF OTHER HEAT-ENGINES.

WHEN heat is liberated on the combustion of coal on the grate of a boiler, it is absorbed by the fine-gases which have been formed in the process of combustion, and these, flowing over the heating surface of the boiler, give off heat, while they are cooling, to the water in the boiler. The steam thus produced is conducted to the engine, in the cylinders of which it expands. In doing this, a part of the heat stored up in the steam is transformed into mechanical work.

Thus the two processes—combustion, or heat-production, and the transformation of the liberated heat into mechanical work—do not take place, in the case of steam-engines, at one and the same place; no less than two heat-carrying media—*flue-gases* and *steam*—are required for the transport of the heat liberated on the grate to the engine proper.

In the case of internal combustion engines, on the other hand, both processes take place in the cylinder itself, the cylinder forming, so to say, a closed fireplace in which the fuel which has been put in is, at short intervals, more or less suddenly consumed. The gaseous products of combustion hold the heat thus liberated, and, as in the case of the steam-engine, a part of this heat is transformed into mechanical work during the following expansion. The steam-engine may, therefore, be said to work with an *open fireplace*, but the internal combustion engine, on the other hand, with a *closed one*. In the first-named group of heat-motors we may also include *hot-air engines*.

## 2 INTERNAL COMBUSTION ENGINES AND GAS-PRODUCERS.

In gas- and oil-engines it has been found possible to transform a far greater proportion of the heat-energy of the fuel into mechanical work than is the case with the steam-engine. With regard to the latter, it might be supposed that this must depend upon the losses which arise in the process of steam-generation, such as incomplete combustion, loss through the escape of the flue-gases at a comparatively high temperature, the radiation or heat from the boilers, and the losses of heat in the pipes, etc. In well-constructed and well-superintended machinery these losses are relatively small in comparison with the losses in the actual transformation of heat into mechanical work in the cylinders. 18 to 20 per cent. of the heat stored up in the steam is, under the most favourable conditions, utilised there; the remainder is to be found in the hot water from the condenser.

The utilisation of heat in the case of the steam-engine amounts, therefore, at the very most, to 13-15 per cent. (cf. note on p. 101), inclusive of the loss of heat in the boiler and in the pipes. In order to increase this percentage, we should, in accordance with thermodynamics, increase the difference of temperature between the live and the exhaust steam. The temperature of the exhaust steam can never be lowered below that of the cooling water, and, for practical reasons, we have to be contented with a lowest temperature of the steam which is about 35° to 70° F. above that of the cooling water. The raising of the live steam temperature and the accompanying rapid increase in the pressure of saturated steam, on the other hand, occasion, in many types of boilers, great inconveniences with respect to safety and cost, which are not balanced by the gain in thermal efficiency.

As an increase in steam pressure is not accompanied by any specially great gain in the consumption of fuel, recourse has been had increasingly of late years to superheating the steam, i.e. to increasing its temperature before it enters the engine. The gain in consumption of steam and of fuel obtained by means of superheating is far greater than that calculated according to thermodynamics, dependent, in the greatest measure, on the fact that superheated steam is not so easily condensed on contact with the colder walls of the cylinder as saturated steam.

In the case of gas- and oil-engines, on the other hand, where the high pressures arising from the combustion occur only in the cylinder itself, it is easier to control them. The injurious effects on the cylinder material and on the lubrication of the piston caused by the high temperatures are almost entirely obviated by cooling the cylinder with water, a process which, however, causes a considerable loss of heat. Another great loss is caused by the exhaust gases leaving the motor at a comparatively high temperature. The losses mentioned, together with that arising from more or less incomplete combustion, reduce the thermal efficiency of internal combustion engines in a very high degree. In spite of this fact, however, these engines transform a considerably larger proportion of the fuel heat into mechanical work than steam-engines do.

## CHAPTER II.

### THE PRODUCTION, PREPARATION, COMPOSITION, AND QUALITIES OF THE FUELS MOSTLY EMPLOYED IN GAS- OR OIL-ENGINES.

THE fact mentioned in the first chapter with respect to gas- or oil-engines, viz. that the combustion takes place in the cylinder itself, in a very short time, necessitates the introduction of *gaseous or very finely divided fluid fuel* in order to bring about that intimate inter-mixture of air and fuel which is absolutely necessary for complete combustion. There can thus be no direct combustion of solid fuel in the engine, but it is absolutely necessary to produce combustible gas out of the fuel, that gas being afterwards consumed in the engine.

It is true that attempts have been made to obtain direct combustion of coal in the cylinder, but this has proved to be almost impossible, partly from the difficulty of feeding in the finely pulverised coal in exactly the proper quantity, and partly from the difficulty of preventing unburnt particles of coal, as well as the ashes, which always remain even after complete combustion, from collecting in the cylinder, which is thus worn out earlier than need be.

If we confine ourselves to the fuel as it is fed into the engine, we see that only *gaseous or liquid fuels* can be consumed there to advantage. Both kinds of fuel must likewise, as will be shown below, satisfy a fairly large number of requirements in order that we may be able to count on obtaining a reliable and economic operation. Thus, the gaseous fuel ought to be such that it can easily be mingled with air, and it must be readily ignitable at the compression pressures employed in the ordinary gas-engines.

By being suitably treated in mechanical and thermal respects, good qualities may be imparted to the fuel which it did not originally possess, and thus its employment in the engine rendered possible. The gas coming from the producer is, for example, well cooled at the same time as it is carefully freed from mechanical impurities, such as coal-dust and ashes, as well as from tar or tar-forming substances. If certain kinds of fuel are employed, the last-mentioned impurities can sometimes be removed during the production of the

gas; a still commoner method is to choose suitable solid fuel, so as to avoid the production of the impurities in question.

Finally, *fuel economics* require that, in general, only such fuels shall be employed as have a low *heat-price*. The heat-price of any kind of fuel is calculated on the available amount of heat which is obtained, on complete combustion of a given weight or volume unit of fuel, together with the cost of the same unit; the heat-price is then suitably stated in pence, or cents, per one million B.T.U. (cf. p. 5).

It will be seen from what follows below, that here, as in thermal calculations in general, we must not introduce the whole of the amount of heat<sup>1</sup> developed when the weight or volume unit of fuel is completely consumed.

In the gaseous products of combustion from a combustible substance, there is generally present steam, derived from the moisture in the original fuel and from the water formed in the process of combustion. During the combustion, a certain amount of heat is absorbed for the evaporation of this moisture, and, whether the products of combustion give off their heat in passing around a boiler, or whether they are allowed to expand in the usual way in the cylinder of a gas- or oil-engine, *this latent steam-heat is technically without value*. For, in the conduction or transformation of heat into mechanical work, the exhaust temperature of the gases will, in both cases, considerably exceed that of saturated steam, corresponding to the pressure the latter has in the escaping gases. Steam, therefore, never has an opportunity of giving off its latent heat to any useful purpose by means of condensation.

Suppose, for example, that we have two gas- or oil-engines of the same thermal efficiency (cf. p. 272), but run on different fuels, both of which liberate the same amount of heat on complete combustion. If the one fuel gives rise to a larger amount of steam than the other, then that engine which has to transform the calorific energy of the former fuel into work must use more fuel per work unit than the other engine.

Thus, incorrect conclusions could be drawn in respect to the capability of the engines to utilise heat, if the whole of the heat developed were taken into calculation, according to weight or volume units. It will therefore be necessary, first, to subtract from the said amount of heat that part which is absorbed by the steam in the fuel-gases, and in modern heat-engines cannot, for physical reasons, be transformed into work. The remainder thus obtained will, in the following pages, be termed the *effective heating value of the fuel*.<sup>2</sup> Thus, had the engines in the above example been run instead on fuels showing the same effective heating values, the amount of fuel used would have been the same for both engines. In judging

<sup>1</sup> Called the *higher calorific value* of the fuel.

<sup>2</sup> Also called *lower calorific value*

| Fuel                     | Effective Heating Value.        |        |                          |       |      |        | Cost of Fuel.          |         |    |    |        |                           | C.S.A. |
|--------------------------|---------------------------------|--------|--------------------------|-------|------|--------|------------------------|---------|----|----|--------|---------------------------|--------|
|                          | Per                             | B.T.U. | Per                      | s.    | d.   | Per    | 1,000 cub. ft.         | Per     | s. | g. | cents. | Per Million B.T.U. cents. |        |
| Illuminating gas         | Cub. ft. at 14°7 lbs and 32° F. | 56.5   | 1,000 cub. ft.           | 1-2   | .    | 21-42  | 1,000 cub. ft.         | 1-25    | .  | .  | .      | 177                       | .      |
| Anthracite               | lb.                             | 15,000 | Ton of 22,40 lbs.        | 25-35 | .    | 1-12   | Ton of 2009 lbs.       | 0-75-10 | .  | .  | .      | 25-33                     | .      |
| Coke                     |                                 | 12,000 | "                        | 12-25 | .    | 51-11  | "                      | 180-550 | .  | .  | .      | 75-23                     | .      |
| Bituminous coal          |                                 | 11,500 | "                        | 6-12  | 3-51 | 15     | "                      | 0-75-8  | .  | .  | .      | 3-25-35                   | .      |
| Heavy oils, such as Tgas |                                 | 18,000 | Gallon of 277.3 cub. in. | 21    | .    | 15     | Barrel of 42 gallons   | 0-80-10 | .  | .  | .      | 13-7-17.1                 | .      |
| Roumanian oil            |                                 | 18,060 | "                        | "     | 4    | 231    | "                      | "       | .  | .  | .      | "                         | .      |
| Paraffin=kerosene        |                                 | 18,000 | "                        | "     | 4-6  | 261-40 | Gallon of 231 cub. in. | "       | .  | .  | .      | 47-5                      | .      |
| Petrol                   |                                 | 18,360 | average                  | 110   | .    | 1      | "                      | "       | .  | .  | .      | "                         | .      |
| Gasoline                 |                                 | 18,360 | "                        | 12    | .    | 1      | "                      | "       | .  | .  | .      | 351                       | .      |
| Benzine                  |                                 | 18,360 | "                        | "     | 1    | 10     | "                      | "       | .  | .  | .      | 99-353                    | .      |
|                          |                                 |        |                          |       |      |        |                        |         |    |    |        | 87-5                      | .      |

<sup>1</sup> 86° Baumé =  $\frac{145}{145 - 1.05}$  specific gravity      35 cents.  
 70°      = 0.702      13.5      (Prices at Milwaukee, Wis., in 1910 if Purchased  
 64°      = 0.724      11      in quantities not less than 10 barrels.)  
 58°      = 0.747      10      "

the fuel-economics of heat-engines, we have, therefore, to take into calculation the effective heating values of the fuels in question.

In Table I., page 5, are given the calculated heat-prices of the fuels most in use. The lower prices of the fuels refer to the conditions at the coal mines, or at the oil-wells, while the higher give the cost of fuel at places which are at a considerable distance away. From this table it appears that the heat-prices of the solid fuels given are considerably lower than those of illuminating gas and of the liquid fuels, and, consequently, the possibility of competition seems to be far greater for the former than it does for the latter.

If we take into consideration, however, that a gas-engine cannot utilise the calorific energy of a solid fuel until this fuel has been gasified, the condition of things will appear quite different. To begin with, during the production and preparation of the gas an amount of heat is lost, amounting, in ordinary cases, to 25-30 per cent. of the disposable heat, inclusive of the losses during the cessation of work. If we add the annual interest and depreciation, calculated on the cost of the producer plant, together with the cost for attendance and upkeep of the plant, all per one million B.T.U., to the theoretical heat-price, we obtain the real heat-price of the gas got from the solid fuel—figures which considerably exceed the theoretical ones.

The pages immediately following are devoted to an account of the production, preparation, composition, and qualities of the different fuels.

## I. GASEOUS FUELS.

Of this class of fuel the kinds most commonly used are *illuminating-gas*, *producer-gas* ("power-gas"), *blast-furnace gas*, and *coke-oven gas*.

### (a) Illuminating-Gas.

Illuminating gas is produced by dry-distillation, i.e. by the heating of bituminous coal without the admission of air.

This gas, as obtained from the mains of the gas-companies, forms an excellent fuel for gas-engines, well purified as it is from tar and mechanical impurities. Its composition varies pretty considerably, according to the quality of the coal used, the manner in which the distillation of the by-products is carried out, etc. In the course of production, a valuable combustible by-product is obtained, viz. *coke*, of which about 20 per cent. is used for heating the retorts. 100 lbs. of coal are estimated to give, as a rule, 480 cubic feet of cooled gas.

Some analyses of city illuminating gas are given below:—

FUELS EMPLOYED IN GAS- OR OIL-ENGINES.

TABLE II.

| Constituents of the Gas.  | Average in per cent. volume<br>of City Gas <sup>1</sup> |           |            |
|---|---|-----------|------------|
|   | London.   | New York. | Stockholm. |
| Carbon dioxide  | CO <sub>2</sub>   | 3.5       | 1.0        |
| Nitrogen  | N   | 5.0       | 4.1        |
| Oxygen  | O   | 0.3       | 0.5        |
| Carbon monoxide   | CO  | 3.7       | 29.8       |
| Methane   | CH <sub>4</sub>   | 38.6      | 18.6       |
| Heavy hydrocarbons  | C <sub>n</sub> H <sub>m</sub>                           | 4.5       | 13.0       |
| Hydrogen  | H   | 47.9      | 30.5       |
| Effective heating value per cubic<br>foot at 14.7 lbs. and 32° F.<br>(B.T.U.) | 596   | 583       | 536        |

<sup>1</sup> Carburetted water gas (see below).

Its effective heating value (at 14.7 lbs. pressure per square inch and 32° F.) generally varies between 575 and 685 B.T.U. per cubic foot. The volume per lb. of gas is 30 cubic feet at the same temperature and pressure. Thus the effective heating value per lb. of gas will be 30 × 575 or 30 × 685 = 17,250 or 20,550 B.T.U. respectively. Theoretically, 1 cubic foot illuminating-gas requires about 5.5 cubic feet, or 0.14 lb. air for its complete combustion. Hence, 1 lb. of the gas needs 13.2 lbs. air.

Of late years, illuminants are often added to so-called *water gas*, made by passing steam through incandescent coke. The composition of this *carburetted water gas* is subject to great variations. Its effective heating value is 550–620 B.T.U. per cubic foot (cf. Table II.).

(b) Producer-Gas.

The employment of illuminating gas for power purposes has diminished more and more of late years, since it has been found possible to obtain from certain solid fuels, by means of producers, or generators, as they are also called, gaseous fuels suitable for gas-engines, and which, in spite of the cost of production, permit of far lower working expenses than those necessary when illuminating-gas is used. The desire to make gas-engine plants independent of the municipal or other gas-works has probably also contributed, in no small degree, to the establishment of private plants for power purposes. The gas obtained in such cases is the so-called *producer-gas*, or *semi-water*

*gas, which is obtained by the incomplete combustion of either distilled or undistilled fuel in air mingled with steam.*

The process can best be made clear by a comparison with the method of production of the original *Siemens producer-gas* (*air gas*), which is made by the incomplete combustion of the fuel in air alone.

In speaking of the production of illuminating gas, we stated how this was made by heating bituminous coal without the admission of air, the final products consisting of a combustible gas, and a solid combustible coke, in addition to tar and gas-water. The coke, in turn, can, with the exception of the ash and clinker, be transformed into gas by means of combustion. If, in this process, the combustion be complete, the final constituents of the gas will not be further combustible. If, therefore, the gas is to be combustible, this end is attained by so restricting the inflow of air, that the combustion will be incomplete.

These two processes, the driving out of combustible gases from the raw fuel by the help of heat alone, i.e., by *dry distillation*, and the incomplete combustion of the coke remaining from the preceding process, take place in the ordinary *gas-producer* when it is charged with undistilled fuel.

A producer, in its simplest form, consists of a high fire-brick furnace, enclosed at the bottom by a grate with a closed ash-pit underneath, and provided at the top with a charging apparatus, permitting of the fuel being introduced from above without the admission of air. From the upper part of the producer the gas generated is carried away through a *gas-discharge pipe*. The furnace is kept filled almost in its entirety with coal, resting on the grate. The air necessary for combustion is, in order to overcome the resistance in the high column of coal, forced under the grate at a certain pressure.

Now, if the producer be charged with ordinary bituminous coal which gradually sinks during the gasification, it is clear, for the first thing, that the temperature in the different layers of coal, during the continuance of the process, cannot be the same. If we follow the combustion air through the producer, we find that the temperature, with the grate as starting-point, steadily increases upwards until, at a certain point above the grate, the highest temperature is reached. The combustion air is sufficient, during this distance, almost entirely to consume the coal, the conditions being analogous with those prevailing on an ordinary horizontal grate with a thick fire. The temperature in such a fire is lowest close to the upper edge of the grate, in consequence of the excess of air being greatest there, and because the fuel and the air are not pre-heated to such a high degree as they are within the fire itself. The fuel in that part of the producer of which we are now speaking consists, to the greatest extent, of coal which, by complete combustion, and while at the same time developing great heat, unites with the oxygen of the air to form *carbon dioxide*. In that layer of coal where the temperature is highest the excess of air must, in accordance with what has been said above

be nil, i.e., the coal has here consumed the last remains of the oxygen of the combustion air.

The superincumbent layers of coal, however, become incandescent in consequence of the hot gases of combustion which stream upward, and chiefly consist of carbon dioxide and of nitrogen from the combustion air. When the carbon dioxide comes into contact with the glowing coal, it is reduced to *carbon monoxide*, which is combustible. It is clear that the formation of carbon monoxide can continue uninterruptedly, as the heat consumed in the process of reduction is constantly replaced from below.

*The reducing layer of coal* has immediately above it *the dry-distilling raw coal*. Even on the border between the two, the temperature is so low that reduction of carbon dioxide can continue no longer. At that height above the grate all the carbon dioxide should, therefore, have become finally reduced, in order to avoid loss by the escape of incombustible carbon dioxide.

Finally, *dry distillation* too is kept up by means of heat from the gases rising from beneath, and the first step in the process is *the expulsion of the water in the form of steam* near the top, after which come *the heavier tar-forming hydrocarbons* and the *lighter hydrocarbons* and the *hydrogen*, which latter are formed and driven out lower down in the layer.

The chemical and physical processes in the decomposition of a solid fuel, in an ideal producer blown with air, thus take place in three zones, which, reckoning from above, may respectively be called the *dry distillation*, the *reduction*, and the *combustion zones*.

The gas which streams out through the gas escape-pipe would, then, chiefly consist of *carbon monoxide*, *hydrogen*, and *hydrocarbons*, which are combustible, and the inert *nitrogen* from the combustion air. In reality, we obtain a gas of another composition, which differs from that just mentioned by the presence of *carbon dioxide*, which has left the producer unreduced. The zones,  $\therefore$ , are not sharply distinct from each other. The difference between the actual and the ideal composition of the gas is partly the result of the temperature in the producer being too low, and partly to be ascribed to imperfections in the physical qualities of the fuel, or to its uneven size, etc., all of which produce irregularities during the process of gasification.<sup>1</sup>

How the formation of the carbon monoxide depends on the temperature is clearly shown by Boudouard's experiments, in which the reduction intensities for carbon dioxide in the presence of incandescent coal are determined within the interval temperatures of 842°–1922° F. The results are shown in Table III., below.

<sup>1</sup> The term *gasification* is used in the following pages as a general expression for the production of combustible gas out of a fuel, while, on the other hand, the term *distillation* is intended to mean the drying and dry-distilling of a fuel.

TABLE III.

| Temperature. |      | Amount of carbon monoxide in per cent. of carbon dioxide + carbon monoxide. | Amount of carbon dioxide in per cent. of carbon dioxide + carbon monoxide. |
|--------------|------|---|--|
| 450          | 842  | 2   | 95   |
| 500          | 932  | 5   | 95   |
| 550          | 1022 | 11  | 89   |
| 600          | 1112 | 23  | 75   |
| 650          | 1202 | 39  | 61   |
| 700          | 1292 | 58  | 42   |
| 750          | 1382 | 76  | 24   |
| 800          | 1472 | 90  | 10   |
| 850          | 1562 | 94  | 6  |
| 900          | 1652 | 96.5  | 3.5  |
| 950          | 1742 | 98.5  | 1.5  |
| 1000         | 1832 | 99.3  | 0.7  |
| 1050         | 1922 | 99.6  | 0.1  |

With a well-heated producer, the prospect of obtaining gas which is richer in carbon monoxide is, thus, greater than when the temperature is low.

The physical qualities of coal which disturb the regularity of gasification arise, for the most part, from the mineral components of the fuel which give rise to *clinker*. In some kinds of coal this becomes pasty, and adheres to the brickwork forming hard projections, which, as a rule, can only be removed with great difficulty from above with an iron bar. Even if the coal, on being heated, gives a hard, coherent clinker, the formation of clinker will, to a certain degree, be a hindrance in a producer.

If, on the other hand, the producer be charged with caking coal, there can easily arise channels in the fuel, through which the carbon dioxide can rush up without being reduced, together with air, which latter may sometimes oxidise a part of the carbon monoxide, formed in the reduction zone, to carbon dioxide. The result will be a gas rich in carbon dioxide and of low heating value.

For reasons easy to be understood, the complete transformation to carbon monoxide ought to be facilitated by the use of coal of uniform but not too large size, and by taking care that the producer is charged to different heights, according to the variation in the size of the coal.

Thus, for example, Strache, in his experiments with a coke producer, found that the equilibrium between the production of carbon dioxide and of carbon monoxide in the unevenly tempered layers of the producer did not show the same dependence on temperature as

that shown by Boudouard's laboratory experiments. The cause of this less favourable agreement is, most probably, to be found in the large size of the lumps of coke, or when the fuel consisted of small coal. Strache was able to confirm Boudouard's results. In the former case, the great spaces in the fuel facilitated the passage of the carbon dioxide and of the air, whereby part of the gas was reduced at a point farther up than in the other, and the oxygen was given the opportunity of entering into a union with the carbon monoxide so as to form carbon dioxide, which, however, was perhaps reduced to carbon monoxide again by the incandescent coal.

It is thus clear that, in one and the same layer, the proportion existing between the amounts of carbon dioxide and of carbon monoxide incessantly changes, for which reason, and especially when the fuel consists of large coal, high producers are, in practice, preferably employed, as a protection against the production of a gas too rich in carbon dioxide.

By simultaneously blowing in *air* and *steam* it is, however, possible to counteract the formation of high temperatures in a producer, with the consequent floating about of the clinker. Instead, the clinker becomes hard and cohesive, and thus easier to remove. The combustion air must not, however, carry too much steam with it, or then the producer temperature may sink so low that the reduction of the carbon dioxide is counteracted. This seems to be the case, at least, when the highest temperature in the producer is less than 1650° F.

When the steam passes through the lower incandescent coal-layers in a producer, it is dissociated into *hydrogen* and *oxygen*, and the latter unites with the carbon, at temperatures exceeding 1650° F., to form *carbon monoxide*; otherwise the decomposition takes place mostly into *carbon dioxide* and *hydrogen*. The hydrogen passes out without further chemical reaction. Thus, in general, steam, in the gasification, gives rise to *carbon dioxide*, *carbon monoxide*, and *hydrogen*, during which process a part of the carbon dioxide, together with a part of that formed by the combustion of the coal, is reduced to carbon monoxide.

The gas thus formed by the simultaneous blowing in of air and steam is called *producer-gas*, sometimes also *semi-water gas*, and has come into very extensive use, especially in metallurgy and for power purposes. Compared with Siemens gas, the composition of producer-gas should, in accordance with what has been said above, show a somewhat larger percentage of carbon dioxide, and is well enriched with hydrogen, which contributes greatly to raise the effective heating value and to give the gas greater lighting power (cf. Tables IV. and V.).

Producer-gas leaves the producer with a comparatively lower temperature than is the case with the Siemens gas, the reason being that the steam requires heat for its decomposition. This heat being taken from the heat-supply of the producer, the result must be a

lowering of the temperature of the escaping gas. The heat which disappears will be found as chemically bound heat in the hydrogen obtained, and is regained on the combustion of the producer-gas in the working cylinder of the engine. The greater percentage of carbon dioxide of the gas is of no great importance of itself, as the great amount of heat which is developed during the complete combustion of the coal can be utilised again by the decomposition of a larger amount of steam. The comparatively low temperature in a semi-water gas-producer has a good effect, too, on the condition of the brick-work of the furnace, while, at the same time, the cooling steam prevents the grate, fire-bars, and other heavier fittings from being burned away.

Finally, the losses due to *conduction and radiation* are less with such a producer than when the gasification takes place with air only.

From what has been said about producer-gas, it is evident that the mixture of combustion air with steam must be regarded as a very successful measure, both from the point of view of safety in working and of heat-economy.

As regards comparative experiments with the two methods of production, a brief account may be given of two made by K. Wendt, as they not only show very clearly the differences in the gas-composition and in effective heat, but they also clearly illustrate the importance of the producer-gas method from the point of view of economy. The accompanying detailed heat balances will be specially useful in the study of the employment of the method for the driving of gas-engines.<sup>1</sup>

The one experiment was carried out with a Siemens producer provided with a fan driven by a steam-engine, so as to provide the producer with combustion air under pressure. During the experiment the producer grew very hot, thereby causing difficulties in working owing to the formation of clinker. In the second experiment we find a producer used where the air is forced in under the grate by a steam-injector. The steam is formed in a little boiler, and is led from there into the upper part of the producer, in order to be superheated in some spiral tubes up to an average temperature of 670° F.

The principal results obtained by the two investigations are summarised in Tables IV. and V. below.

<sup>1</sup> Z. Ver. deutsch. Ing., 1904, p. 1793.

TABLE IV.

| List of Tests.  |        |          | II.     |
|---|--------|----------|---------|
| Duration of tests, in hours                             | 51     | 31       |         |
| Coal consumption, in lbs. per hour                      | 602    | 469      |         |
| Amount of steam blown in, per 100 lbs. fuel, lbs.       | 26.3   | 26.3     |         |
| Composition of gases in vol. per cent.                  |        |          |         |
| Carbon dioxide  | CO     | 0.85     | 5.40    |
| Carbon monoxide   | CO     | 30.65    | 27.01   |
| Light hydrocarbons                                      |        | 2.55     | 2.93    |
| Hydrogen  | H      | 7.10     | 14.55   |
| Nitrogen  | N      | 58.85    | 30.11   |
| Exhaust temperature of gas                              |        | 1180° F. | 984° F. |
| Effective heating value of gas per cub. ft. cleaned gas | B.T.U. | 152      | 163     |
| Impurities in 1000 cubic feet gas.                      |        |          |         |
| Water   | lbs.   | 4.41     | 5.44    |
| Tar   | "      | 1.12     | 0.96    |
| Dust and soot   | "      | 0.39     | 0.06    |

The coal used contained on an average 58 per cent. carbon, 9.7 per cent. moisture, and 18.1 per cent. ashes. The effective heating value (at 14.7 lbs. pressure and 32° F.) was 9616 B.T.U. per lb. 1 lb. coal yielded, in the first instance, 41.3 cubic feet gas with an effective heating value of 152 B.T.U. per cubic foot, but, in the second case, 45 cubic feet gas at 163 B.T.U. per cubic foot.

In comparing the heating economics of the two producers we are, of course, obliged also to bear in mind the amount of heat required for the production of the steam necessary for the two processes. In the case of the producer first mentioned, only an inconsiderable amount of steam was required for driving the fan, while the consumption of steam for the producer-gas was considerable (26.3 lbs. steam per 100 lbs. coal). It is true that much of the heat from the coal which was consumed on the grate of the boiler was transmitted to the steam, and thus, after deducting the heat-losses in the piping, was a gain to the producer; the remainder of the heat, on the other hand, was employed in covering the heat-losses of the boiler.

Under such circumstances the heat-balances for the two producers are as shown in Table V.—

TABLE V.

| List of Tests.                          | per cent. | I.     | II. |
|---|-----------|--------|-----|
| (1) Heat used on grate of boiler        | 0.28      | 4.86   |     |
| Latent effective Heat in :              |           |        |     |
| (2) Cleaned and cooled gas              | 70.06     | 73.05  |     |
| (3) Tar                                 | 7.15      | 5.95   |     |
| (4) Soot                                | 0.35      | 0.05   |     |
| (5) Unburned coke, free from slag       | 3.82      | 2.35   |     |
| Free Heat in                            |           |        |     |
| (6) Impure gas                          | 11.72     | 9.67   |     |
| (7) Ashes, clinker, unburned coke, etc. | 0.10      | 0.08   |     |
| (8) Radiated Heat                       | 6.51      | 4.19   |     |
| Total.                                  | 100.00    | 100.00 |     |

In order to judge correctly of the heat-economy in both cases, we must first take into consideration the use that is to be made of the gas. In many cases, gas-fuel can be used in the furnace without any preparatory cleaning and cooling, and in the most favourable circumstances all the quantities of heat given in 2, 3, 4, and 6 can be utilised, the free heat, it is true, being contingent on the furnace being in the immediate vicinity of the producer. The efficiency should in such circumstances amount to as much as 89.29 per cent. in the former case, and 88.72 per cent. in the latter; i.e. the fuel-economy will be about as good in both producers.

On the other hand, the only *suitable fuel for gas-engines* is cooled gas, from which the dust, soot, and tar have been carefully removed; and so, in this case, is only the remaining latent heat in 2, of which there can be any question, amounting to 70.06 and 73.05 per cent. respectively of the effective heating value of the fuel. Under this assumption, the producer-gas method gives a better result than the original Siemens process. With respect to the use of the gas for motor purposes, it is further shown by Table V. that, in the second test, the generation of steam demanded a considerable amount of heat, and the substitution of free gas-head for this, in accordance with later improvements in producers, should greatly contribute to the increase in efficiency.

As regards the loss of heat in, in consequence of the separation of tar, i.e., the heavy hydrocarbons, it increases in general with the proportion of hydrocarbon compounds borne by the fuel, except when the gasification, as will be shown later on, is carried out on the principle of transforming these compounds into lighter non-condensable gases. In the greater number of producers used for power

purposes, the fuel, however, is gasified without any departure from the ordinary producer-gas method, for which reason only fuels poor in hydrocarbons can be used with advantage, from the point of view of heat economics. It is easy to explain the high efficiencies of 80-85 per cent. which are often reached in modern producers, when the improvements mentioned and the great care with which fuels are often chosen are taken into account.

As was said just now, the raw gas from a producer must be cooled and carefully cleaned before it is used in the engine. In this process, an endeavour should be made to secure the most effective cooling of the gas possible, chiefly in order to reduce its volume, whereby a greater power will be obtained from a gas-engine of given cylinder dimensions than if, on entering the cylinder, the gas be at a comparatively high temperature. The colder gas contributes, too, to the cooling of the inner walls and valves of the cylinder, and permits, without inconvenience, of the employment of high compression.

It need hardly be said that mechanical impurities in the gas, such as dust, soot, ashes, etc., will have an injurious effect on the walls of the cylinder. Tar, on the other hand, deposits itself mostly on the valves, which are thereby hindered from closing tightly, or it makes the valve-stems stick.

It is true that it is possible to gasify ordinary bituminous coal and, by means of thorough cleaning, to make raw-gas into engine-gas, although the heavy tar-vapours are very unpleasant mixtures to have to deal with, even if the best cleaning apparatus is used, for this apparatus has often to be cleansed from the sticky tar-products which arise from the condensation of the tar-vapours, which, together with the cleaning-water, form a smelling, soapy emulsion which causes much trouble and interrupts the working.

Even if, with the help of the most effective cleaning apparatus comparable with that used for the preparation of illuminating gas, it were possible to get from ordinary bituminous coal a gas which as far as composition went was quite fit for use, the formation of clinker, with its disturbing influence, which is often very great, would still have to be dealt with. A producer which is to supply gas to a gas-engine should always be able easily to supply the amount of gas which may be necessary at any given time. The gas should also be of good and fairly constant quality at all loads, so that the engine will not be in continual need of adjustment. These conditions, so absolutely indispensable to thoroughly safe and economical working, are often very imperfectly fulfilled when the fuel consists of bituminous coal. Here it is the previously mentioned bad qualities of the coal—such as caking, giving off liquid clinker, etc., in the presence of heat—which in such a high degree render the maintenance of a sufficiently large, effective and properly tempered reduction-surface of the coal a matter of such difficulty. On this account it sometimes happens that the capacity of the producer is occasionally so far lowered that the working must be stopped for some time.

It is true that the provision of a sufficiently large reserve would contribute to the adjustment of the variations in the amount and composition of the gas, but this has the inconveniences that it increases the cost of construction and that there is a greater consumption of coal, as compared with engines where a reserve can be dispensed with.

As the cost of construction and upkeep in working with producer-gas obtained from coal rich in hydrocarbons, and the more or less uncertain and uneconomical working based on the use of this gas, have thus contributed their share to check the more general adoption of such plants, it has been almost exclusively such kinds of coal as are poor in hydrocarbons that could be used. It was the untiring efforts of the last few years to find a producer that was capable of gasifying any kind of fuel, that first gave rise to producers whose construction renders it possible economically to produce "power-gas" out of a number, at least, of fuels rich in hydrocarbons. As these methods, together with the apparatus belonging to them, present, on comparison, fairly important differences from those intended for fuels poor in hydrocarbons, the former and the latter methods and apparatus will be treated separately.

We must, to begin with, consider certain arrangements which are common to both methods of production, viz., those intended for the generation of steam, and for the leading of the combustion-air mingled with steam into the producer.

The producer described above got its supply of steam from a little boiler which was heated separately. Although the steam was blown in together with air and, in accordance with what was shown there, the temperature of the issuing gases was thereby essentially lowered, we can convince ourselves, however, by casting a glance at Table V., that still nearly 10 per cent. of the effective heating value of the fuel can be found in the form of free heat in the gas that passes out. When the gas is cleaned, this amount of heat is of course lost, going off with the lukewarm water that runs off from the cleansing apparatus.

From what has been said above, it would be useless to endeavour to diminish the said loss of heat by not cooling the gas as much as possible during the process of cleaning. The plan would then present itself of letting the gas give off its free heat to a useful purpose before passing the cleaning apparatus, viz., the generation of the amount of steam that is necessary. The following simple calculation shows that, in ordinary cases, the amount of heat the gas takes with it out of the producer is really sufficient for this purpose.—

The gas from a semi-water gas-producer has, when it issues, a temperature usually exceeding 840° F. If the specific heat of the gas<sup>1</sup> is taken at 0.0187, and the yield so low as 77 cubic feet of gas (at 14.7 lbs. and 32° F.) per 1 lb. of fuel (which can easily be obtained with anthracite), there is thus obtained (under the supposition that the

<sup>1</sup> That amount of heat, in B.T.U., necessary for raising the temperature of cubic foot of gas (reduced to 14.7 lbs. and 32° F.) through 1° F.

gases leave the vaporiser at  $300^{\circ}$  F.), for 1 lb. of gasified fuel, not less than  $77 \times 0.0187$   $(840 - 300) = 778$  B.T.U. available for steam production.

The proportion between the amounts of fuel and of steam differs very much in different plants. Above all, it is the quality of the fuel, the way in which the regulation of the water supply is carried out, the construction of the gas-engines, and other circumstances, which are the cause of this. In ordinary plants, the weight-relation between the steam and the fuel amounts in general is  $0.3:0.7$ . For reasons which will be mentioned below, the formation of steam in the vaporiser (figs. 13-15 and 18), which is heated by the gas, does not take place under pressure. Also besides, the steam in such plants is usually conveyed to the producers in a saturated condition, and the total heat of such steam being 1147 B.T.U. per lb., there is thus required to produce steam from feed-water at  $70^{\circ}$  F., an amount of heat of  $0.3$  to  $0.7$  ( $1147 - 38$ ) B.T.U., i.e. 333 to 776 B.T.U. per lb. gasified fuel.

With the help of the vaporiser, arranged in the way mentioned above, we can thus regain from 30 to 70 per cent. of the free heat of the gas, which would otherwise be lost in the cleaning-water.

A large number of producers for semi-water gas have also the combustion air supplied pre-heated, the heat being then, too, obtained from the hot producer-gases. In general, therefore, by the introduction of vaporiser and air pre-heater, about 60 per cent. of the free heat of the gases can be regained, which is equivalent to an increase in efficiency of about 6 per cent. In reality, the gain obtained will be considerably greater, those losses being removed which arise from the small, specially fired boilers working with poor efficiency. By the use of the above-mentioned apparatus, it was thus made possible to dispense with the generation of steam under pressure, and the simplicity of the vaporiser made for smaller demands on the skill and attention of the attendant.

In the middle of the decade 1890-1900, *Brenier* and *Taylor* succeeded, on a small scale, in making a producer-gas suitable for motor purposes, with the help of open vaporisers, in which the mixture of steam and air streamed through the producer by the *vacuum* created by the suction of the engine. This gave origin to the so-called *suction-gas plants*, which now have almost entirely taken the place of the older plants working under pressure and with a special boiler. These latter were invented by *Dowson* in 1881, and are usually called after him, "Dowson gas plants" (cf. figs. 17 and 18).

In a suction-gas plant, exactly that amount of gas is prepared that the engine uses for the time being, which, however, in union with the vacuum constantly existing in the producer, renders possible, in a simple manner, the formation of a quantity of steam corresponding to the amount of gas used for the time being, with the assistance of the above-mentioned vaporiser-apparatus. As such an apparatus can, without inconvenience, be put into communication with the outer air, the bringing together of air and steam usually takes place by the

*combustion air being sucked through the vapouriser, in doing which, the air mixes with the steam. The mixture of steam and air is then led, as usual, in under the grate of the producer.*

With pressure-gas plants it was, in general, easier to get gas of a constant composition. The pressure of the steam for the injector does not seem to have had any great influence either on the amount or the composition of the gas generated, and it was possible with the old *Dowson* plants to blow gas of good quality and an even composition, whereby the load could be allowed to vary very considerably without the quality of the gas suffering to any great degree.

Another circumstance contributed doubtlessly to this. The *Dowson* gas plants were constructed in accordance with the style of the old illuminating-gas works, especially as regards the collection of the gas immediately before use; just as an illuminating-gas works is provided with a gas-holder for the collection of the gas when produced, and for producing uniformity in the case of any great variations in pressure or in composition, so one part of a *Dowson* plant, too, was a gas-holder, although it was of smaller dimensions, and was used for other reasons as well.

In the greater number of *Dowson* gas plants, the charging must take place at short intervals, usually 10-30 minutes, if the height of the column of coal in the producer is to remain unaltered, which, in general, is one of the chief conditions for a steady supply of good gas. Now, from tests made with producers at work, we know very well that the effective heating value of gas is subject to periodical variations, which do not arise from uneven loading, faults in the construction or regulation of the vaporiser, or uneven composition of the fuel, etc., but from the charging. After each charging, the effective heating value of the gas diminishes, followed by a rapid increase of the same, after which there is only a slow increase until the maximum is reached, when the heating value again diminishes.

It is evident, therefore, that the gas-holder of a pressure-gas plant, if it was large enough, acted, in some degree, as an adjuster on the composition of the gas, and thus helped to obtain an even and economical working.

Another reason for using the gas-holder with producer-gas plants working under pressure was the following:—

The producer in such a plant does not, as is the case with suction-gas plants, produce gas just to the amount demanded by the load for the moment, but the amount of the gas-development in the case of a *Dowson* gas plant depended in the first place on the admission of steam to the injector. As this could not be easily regulated, either by hand or by any device, so that just the necessary amount of gas should be produced, it was necessary, for the sake of reliability, to provide such a plant with a gas-holder in which a large amount of gas could be collected to serve as a reserve. With the introduction of the gas-holder there also came an automatic regulation of the injector, of which more will be said in the fifth chapter.

In the case of suction-gas producers, a simple method has been found of avoiding the inconveniences which arise in consequence of the periodical charging. The newer producers, at least, are provided in general with a *fuel-hopper* and *fuel-magazine*, whereby the height of the column of coal can more easily be kept constant, and gas of more even quality is obtained, even if the producers are charged at greater intervals of time (cf. p. 70).

The ability of a suction-gas plant to give as much gas as the power demands, is usually strained to the utmost when the load of the engine suddenly jumps up from a low to a maximum one, and remains at about the maximum for a considerable time. If, at the same time, the fuel is of poorer quality, such as dust coal or coking coal, the mixture of steam and air is exposed during its passage through the producer to a considerable resistance, which must be overcome by more powerful suction in the engine itself. The first consequence of this is, that the vacuum in the cylinder of the engine during the suction stroke becomes higher than under normal conditions, for which reason the engine, just when the maximum power is to be given, does not receive the weight of gas corresponding to the load. The consequence is that the engine slows down unless the load is at once reduced.

The pressure-gas plant, on the other hand, possessed, in the high-pressure steam at its disposition, a certain working-reserve for driving forward the mixture of steam and air, a reserve which proved of very great service whenever it had to overcome any great resistance within the producer. But such hindrances in the way of the gas could also arise in the cleaning apparatus and gas-pipes, if for any reason there was a delay in their cleaning, and the steam reserve was thus of service on such occasions too.

Finally, another inconvenience, and one that appears most clearly at maximum loads, depends on the circumstance that air-leaks at the joints, cleaning doors, etc., are not excluded when suction-gas plants are used, as the preparation and cleaning of the gas takes place in a vacuum. The air which leaks in dilutes the gas, and so renders it more difficult to retain the proper proportion in the mixture of air and gas during the period of suction. The leaks need not be very big to prevent the engine from working at heavy loads. But the danger respecting the rise of explosive mixtures between the air and gas in the apparatus and pipes is certainly altogether exaggerated in this case. With ordinary producer-gas such a danger arises only when the proportion between them approaches 1:1, which cannot so very easily happen.

The efforts which have been made during the last few years to increase the reliability of suction-gas plants have had the result that we have gradually learned to calculate the proper areas and other dimensions of the apparatus and pipes; the producer-shafts have become of more convenient form, the cleaning devices have been improved, etc., and all these factors have contributed to the result that

suction-gas plants, in the respects mentioned, may be considered almost as good as pressure-gas plants.

The *advantages* which suction-gas plants have over pressure-gas plants are many and great, and, happily, *greater safety* and *simplicity in attendance* are not the least of them good qualities.

While thus, with a pressure-gas plant, so much of the *poisonous* gas could easily stream out even through small leaks, in consequence of the difficulty of detecting them in time, that in a short period it would be dangerous for the attendants; in the case of a suction-gas plant there would be, in a similar event, at most, a dilution of the gas, and, according to what has been shown above, a diminution in power.

As regards attendance, there is, *in the case of a suction-gas plant, no attention at all to the boiler*, and the *freeing from clinker will be much simpler* than with pressure-gas plants. For, on account of the pressure in the ashpit, the doors of the pressure-gas producer could on no account be opened, for which reason the removal of the clinker was usually carried out when the engine stood still. In cleaning out or removing the clinker from the grate, it was first necessary to put the producer into communication with the outside air by means of the blow-off pipe, and then to shut off steam from the injector. In most cases the engine had to be stopped as well, as the gas-holder of such a plant was not, as a rule, made so big that, when the clinker was being removed, the necessary supply of gas could be covered by one holder-filling alone. The change from pressure-gas to the suction-gas system brought about a considerable alteration for the better as far as regards the cleaning-out of, and the removal of clinker from, the producers. *The grate of a suction-gas producer can be freed from clinker while the engine is at work*, but with the restriction, however, that the cleaning must be done as quickly as possible, chiefly in order to avoid a dilution of the gas by a direct sucking-in of air. As a rule, therefore, suction-gas producers are also freed from clinker after the cessation of work, if possible. For this reason, in the case of plants with long working time and heavy load, use is sometimes made of double producers, which are cleaned alternately.

Finally, *a suction-gas plant requires much less space than a pressure-gas plant of the same capacity*, as there is no need for a boiler and gas-holder; and it is also cheaper to procure and to keep up than a pressure-gas plant.

It is true that disturbances in the running still sometimes occur with suction-gas plants, but, in most cases, these can be explained either by unsuitable fuel having been employed, or by the resistance in the cleaning apparatus and pipes having been too great, while sometimes the gas-plant itself is too small.

The two chief methods for the formation and introduction of the mixture of steam and air into the producer having thus been described, and the advantages and disadvantages of each system having been pointed out, we shall now continue the description (broken off at page 16) of the principal differences which specially characterise the method

of production of such gas, according to whether the fuel employed is rich or poor in hydrocarbon compounds.

### The Production of Producer-Gas from Fuels poor in Hydrocarbons.

Chief among the fuels poor in hydrocarbons are *anthracite and coke*. *Anthracite* consists almost entirely of pure carbon, and thus contains only small amounts of hydrocarbons, and of mineral compounds which tend to form clinker. It is an excellent fuel for producers, this being especially the case with *British anthracite*.

*Welsh anthracite* is the one with the least amount of impurities, for which reason less attention and care is needed with this kind of coal than with *Scotch anthracite*, which sometimes contains considerable amounts of clinker- and tar-forming substances. In spite of the inconveniences which must be encountered when poor anthracite is to be gasified, it not seldom happens, with regard to economy in working, that a better result is obtained with such coal than with the Welsh or closely allied coals. The difference in price between them is the first reason of this; we also now know how to make a better use of the modifications in the construction of the producers and cleaning apparatus which are rendered necessary by the use of a poorer coal. Smaller-sized producers should, in general, be charged with anthracite of better quality.

*The size of the coal* is of importance in choosing fuel. Too small coal easily falls through the air-spaces of the grate, and, in consequence of the great resistance which is offered to the air by the tightly packed coal, it shows a certain disposition to leave the central part of the producer and to pass along the walls instead. Here, then, combustion will be more energetic and the heat greatest, and, in consequence, clinker will easily form along the walls, from which it will be difficult to remove it. In addition to this, the air easily passes along between such projections of clinker, and consumes a part of the gas which has been formed, with the result that the quality of the gas is lowered. If, on the other hand, the coal is too big, the maintenance of an even production of gas will require comparatively large producers; and so, as a rule, anthracite of greater dimensions than *three times the width of an air-space between the fire-bars of the grate* is not generally used.

It is often found advantageous to use a mixture of medium-sized and small coal for charging suction-gas producers, in which means a good mixture can be had at a reasonable price. One should not neglect to find out the kind of coal, or mixture of coal, which, in each special case, gives the most economical result with an average amount of care, and with few or no interruptions.

As the cleaning apparatus is really intended to filter out the coal-dust and soot which accompany the gas, special importance should, as a rule, be placed on getting good anthracite, in order to avoid the troublesome deposits of tar already spoken of. *With purchases of coal in general, one should try to get the dryest possible kinds when*

buying fuel for a producer, and care should also be taken that the coal, when stored up before using, does not get damp.

Thus, from what has been said above, in order to get producer-gas from anthracite in ordinary suction-gas producers, it is suitable to use coal free from dust, and from  $\frac{5}{8}$  inch to  $1\frac{1}{2}$  inch in size, with a small percentage of ash and volatile substances. The effective heating value of such anthracite usually lies between 14,200 and 15,500 B.T.U. per lb.

As regards the composition of producer-gas, when the fuel consists of anthracite, gas-analyses show pretty large divergences, even when one and the same sort of coal is used, for which reason no absolutely definite statement can be made respecting the composition of such gas. A percentage composition, however, would probably be about as follows :—

|                 |               |    |                  |
|-----------------|---------------|----|------------------|
| Carbon dioxide  | $\text{CO}_2$ | 6  | volume per cent. |
| Carbon monoxide | $\text{CO}$   | 23 | " "              |
| Hydrogen        | H             | 18 | " "              |
| Methane         | $\text{CH}_4$ | 1  | " "              |
| Nitrogen        | N             | 52 | " "              |

The yield varies, according to the character of the coal and the efficiency of the producer, as a rule, between 76 and 82 cubic feet gas (of 14.7 lbs. pressure per square inch and 32° F.) per lb. anthracite. The effective heating value of the gas is, on an average, 110 B.T.U. per cubic foot at 32° F., or, as 100 cubic feet of gas weigh 6.75 lbs., about 2080 B.T.U. per lb. The specific weight compared with air is about 0.84. In order to completely consume 1 cubic foot producer-gas of the above composition, there is required 1.1 cubic foot or 0.089 lb. of air, which gives 1.31 lb. air to 1 lb. producer-gas. A producer-gas richer in hydrogen is sometimes found with a lower specific weight and higher heating value (146 B.T.U.), but then pre-ignition not unfrequently occurs in the engine, especially with high compression and heavy load, if the engine has not been specially regulated beforehand for working with such gas.

Coke is chiefly obtained as a by-product in the manufacture of illuminating-gas, or as the chief product on a large scale in coke-ovens, certain by-products of the illuminating-gas obtained being then utilised, unless the gas is put to its ordinary use. In both cases, coal is the raw material. Both kinds of coke, *retort-coke* and *coke made in ovens*, can, as a rule, be used on suction-gas producers. Coke made in ovens is, however, harder and more compact than retort-coke, and does not suffer so much from transport and pressure as the latter, so that it can, without inconvenience, be charged in very lofty shafts, as is the case, for example, with blast-furnaces, etc. Its effective heating value is, in general, higher than that of gas-coke, and coke made in ovens can, therefore, be relied upon to give a higher temperature and, within a certain volume, a greater amount of gas and heat developed, than would be the case if retort-coke was used.

For suction-gas producers, well-washed and carbonised coke is

generally used, containing a small percentage of ash, and about  $\frac{1}{8}$  inch to  $\frac{1}{2}$  inch in size. Coke of lesser dimensions, such as coke drops, pearl-coke, etc., which is obtained by screening oven- or gas-coke, often gives off a large quantity of liquid clinker during combustion, and so there is some difficulty in gasifying such coke in an ordinary suction-gas plant.

The effective heating value lies between 14,000 and 13,000 B.T.U. per lb. Producer-gas obtained from coke is, as a rule, not so enriched with hydrogen as when the fuel consists of anthracite, which is clearly seen by the effective heating value of the gases obtained by using the one fuel or the other. When coke is used as fuel, therefore, we can calculate on 130 B.T.U. per cubic foot gas (at 14.7 lbs. pressure per square inch and 32° F.). Now, 100 cubic feet producer-gas from coke weigh about 7.5 lbs., and thus the specific weight of the gas will be 0.93 as compared with air. Complete combustion of 1 cubic foot of such gas demands, theoretically, at least 1 cubic foot, or 0.081 lb., of air. Thus, for 1 lb. gas there will be needed 1.08 lb. air.

### The Production of Producer-Gas from Fuels rich in Hydrocarbons.

To be restricted to the use of some few solid fuels is evidently attended by a number of inconveniences, such as the variation in price due to variation in the demand. We may take, for example, the case of the better kinds of anthracite, as things are at present in countries which have to import their coal. Apart from possible increases in price, the cost of the kinds of anthracite and coke which are poor in hydrocarbons considerably exceeds what must be paid for ordinary coal; the necessity is seen of being able to gasify coal of varying composition with economy and reliability. And, even if the attempts made during the last few years to construct fully suitable power-producers for bituminous coal have not yet been crowned with any great success, the efforts made in common to obtain producer-gas from any kind of bituminous fuel have had as a result, that two such fuels, *peat* and *lignite*, have been employed far more successfully.

Some kinds of coal, those especially which are closely related to anthracite, have, it is true, been successfully gasified in specially constructed producers, but this was either at very large plants, where it paid to make use on a large scale of a number of by-products from the gas, as the income from these partly paid the working expenses for the production of energy, or else where the utilisation of the gas in gas-engines was of subordinate importance for the plants in question. The comparatively poor efficiency, together with the great expenses for installation and working, have also contributed to restrict their more general adoption; but, above all, it is the great want of adaptability of the coal producer in regard to different kinds of fuel, which is its most striking feature in comparison with the modern steam-plants, which generate cheap steam by means of even the worst kind of coal.

But, even if the method of endeavouring to remove the tar from producer-gas obtained from ordinary coal by means of mechanical

purification can be considered as a way of preparing the said gas for gas-engines, the destruction of the tar-products by their decomposition or combustion in the producer itself must be considered as the only correct principle, in accordance with which it ought to be possible to produce fully usable engine-gas from bituminous fuel. In this method of procedure, the percentage of tar in the gas from peat- and lignite-producers, at least, has not proved to be so great that it has caused any considerable inconvenience. The gain is not, however, confined merely to the obtaining of tar-free gas. By the utilisation of the valuable tar-products for the development of gas, the efficiency of the producer is often essentially increased.

*Decomposition* can be imagined as so taking place that the heavy hydrocarbons are allowed to pass a layer of incandescent coal in the producer, whereupon the compounds are decomposed by the action of the heat and give off carbon, until at last only permanent gases, *methane* especially, remain. This is a gas rich in hydrogen, of low specific weight, and possessing a high effective heating-value.

*If, on the contrary, the heavy gases are burned in air, water and carbon dioxide* are formed, and heat is developed at the same time. If these products of combustion are also allowed to pass through incandescent coal, the carbon dioxide will be reduced to *carbon monoxide*, while the combustion water is decomposed into *hydrogen*, and gives rise to the formation of *carbon monoxide* and *carbon dioxide*, in agreement with the course of the reaction in an ordinary producer for semi-water gas.

In a producer for the production of tar-free producer-gas which is charged with bituminous fuel, both processes usually take place simultaneously if the temperature exceeds about 1800° F., the tar-vapours present being led, together with air, through incandescent coal. The heat arising from the combustion of the tar-vapours is then added to the other amount of heat in the producer disposable for reduction. If, on the other hand, the temperature is considerably lower, the decomposition takes place less completely, which, amongst other things, appears from gas-analyses made with such producers before normal working-conditions have set in.

Very illustrative in this respect are the analyses in Table VI. (p. 37) of gas from a *Koerling peat-gas producer*. From these analyses can plainly be seen, amongst other things, both when normal working conditions set in (marked by the almost total disappearance of the heavy hydrocarbons and by the simultaneous increase of the percentage of carbon monoxide, both of which are manifestations of increased temperature), and also that a comparatively long time elapses before the highest temperature is at all attained in the producer. Although the low heating value of the peat also contributes to the lengthening of the time mentioned, the chief reason is to be sought for in the circumstance that the producer, in the case in question, was quickly taken into use again after a long stoppage. In any case, we see by what has been said above, that the transformation of the tar-

vapours into permanent gases cannot be counted on with full certainty, unless a certain minimum temperature (about  $1800^{\circ}$  F.) is exceeded, but also that, even when it is a question of watery peat as fuel, it is still possible to retain equilibrium in the right composition of the gas.

Finally, a glance at the variations in the effective heating value (see the table) may be of some interest. First, we have to remember the high effective heating value of methane and the heavy hydrocarbons (the latter consisting chiefly of ethylene), which are usually given as 950 and 1580 B.T.U. per cubic foot respectively. Thus, even with a percentage of 6 per cent., methane contributes 57 B.T.U., and the amount of ethylene need only be something over 3.5 per cent. for the same amount of heat to be obtained. From this may still further be seen, first, the importance of utilising the latent heat of the heavy hydrocarbons in the manner before mentioned; and, secondly, that the effective heating value of the gas can show important variations, according as the transformation into permanent gases takes place at a higher or lower temperature, which can be read off from the table at once.

At the first glance it might be imagined that the efficiency of the producer was considerably greater prior to the setting of normal working-conditions than after that time, the gas being considerably richer in heat during the first period than during the latter. But here we must not neglect the greater amount of gas obtained per lb. of fuel during the latter period, whereby the efficiency is increased.

As to the different methods of procedure by the help of which the principle of the serviceable transformation of the hydrocarbons has been realised, these can, in the main, be divided into the following classes:

**I. Gasification in the ordinary way, but with the introduction of the tar-vapours into the zone of combustion.**

The forms of producers belonging to this class are characterised by the feature that the products of distillation are drawn off at the top and are led in a closed outer pipe either beneath the grate (Pintsch producer, fig. 30) or close above the same (Koerting's producer, figs. 27-29). In order, however, to compel the above-mentioned products to follow this roundabout way, and not to risk their being drawn down the producer and on towards the main gas-outlet in consequence of the suction of the engine, there should be, first, a protective hindrance (a column of coal) between the principal and the secondary gas-outlet, and also such arrangements as will permit of a regulation of the suction in the outer pipe. It is of specially great importance that this secondary suction should easily be reinforced in the case of bituminous coal-producers, especially, for there the resistance which the accumulated coal offers to the gas-current, in consequence of the disposition of the fuel to sinter, to give off liquid clinker, etc., can easily grow till it reaches a considerable amount. Thus the firm, Pintsch, makes use of a steam- or compressed-air injector (cf. p. 95).

But in the case of producers intended for such fuels as peat and lignite, the gasification of which takes place more undisturbedly, the construction is a much more simple matter. The manner in which the firm, *Koebing*, manages this regulation consists simply in *throttling the supply of air under the grate to a greater or less degree*, whereby a vacuum is obtained sufficiently high for sucking-off the products of distillation.

**II. Combined producer with ordinary producer for semi-water gas in combination with a specially heated reduction-furnace.**

Fig. 1 shows a section of an experimental gas-plant according to the construction by the firm *Deutz*, in which lignite was gasified in

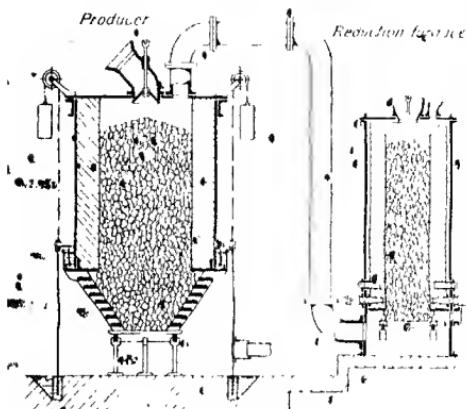


FIG. 1.

agreement with this principle. The tarry gas formed in the producer was carried in under the grate in the reduction-furnace, which was charged with coke. Air was supplied to the oven by means of four *blast-pipes*, lying above the grate, whereby the column of coke became so strongly incandescent that one could be quite sure of a transformation of the tar-products of

the gas taking place. As the lignite used contained a large percentage of moisture—as much as 60 per cent. of water—coke was added to the producer in order to obtain the high temperature necessary for reduction.

With this plant and a 16 H.P. gas-engine installed, there was carried out, towards the close of the year 1899, a series of experiments in order to find out the power capacity of the plant, the purity of the gas, and the fuel economy as a whole. The most favourable result gave a consumption of coal of 2.6 lbs. per B.H.P. per hour, of which 2.1 lbs. consisted of raw lignite and 0.5 lb. of coke, of the latter weight 0.18 lb. went to the reduction furnace. The cleaning of the gas was performed without difficulty, and so perfectly that, after sixty hours' operation, only a very small deposit of tar could be discovered inside the engine.

This arrangement was afterwards improved in accordance with a patent taken out by *Deutz*, in which the producer and the coke furnace are conceived as forming a single producer, provided with a dividing wall in the middle. Ordinary coal was to be gasified in this producer without the use of special reduction fuel. It was, besides, a modification of the so-called *Ekman's* coal-tower, which has been used in Sweden since 1810. The difficulty, already mentioned, attached to the heating of coal, respecting the maintenance of a gasification equable in every respect, was probably the reason why this construction did not come into use.

Of late years, the producers constructed by the French firm, the *Compagnie du Gaz Riché*, Paris, have been much spoken about. They are really intended for the production of tar-free gas out of wood refuse, and consist, in the main, of two furnaces, the *fuel furnace*, provided at the bottom with a step-grate, and the *reduction furnace*, which is kept filled with charcoal. On the grate of the former furnace there is burned the raw fuel, carbon dioxide being developed at the same time, in which process the heat communicates itself to the fuel higher up in the furnace, which is thereby gasified. The products of distillation which are driven out in this manner are taken downwards through the combustion zone, and are there transformed into permanent gases. The whole gas-stream afterwards passes through the reduction furnace, for the purpose of reducing the carbon dioxide to carbon monoxide by the action of the incandescent reduction-charcoal. As the fresh fuel contains a considerable amount of water, no vaporiser is, generally speaking, needed. Coke is also sometimes used instead of charcoal. This type of producer has come much into use in France, and is said to give good results.

*III. Reverse procedure with the air-supply admitted at the top of the producer, but with the gas-outlet at the bottom (inverted combustion or down-draught producers).*

A Frenchman, *Faugé*, makes use of this method for the production of tar-free producer-gas from wood. The producer (fig. 2) consists of a firebrick-lined furnace open at the bottom, under which there is a hearth whose bottom supports the column of fuel in the slate. The combustion-air enters at the top, but, before doing so, it is warmed in a pre-heater, which is heated by the warm gas which escapes. When the producer is in operation, there is formed high up in the fuel a *zone of combustion*, with a highest temperature at a certain depth under the surface (cf. p. 8), and under this zone begins the *reduction zone*. When fresh fuel is charged from the top, it is distilled by coming into contact with the incandescent fuel underneath. The products of distillation, together with the combustion-air, then pass through the *zone of combustion*, in doing which the former are transformed into permanent gases. Otherwise, the gasification takes place in the ordinary way. The gas passes off downwards, as before mentioned,

at a temperature of about 570° F., and is freed from the particles of ash which follow with it in the pre-heater, which, at the same time, does service as a coke-scrubber. All the fuel, however, is not capable of being gasified, and so we have always to calculate on getting a residue of charcoal—about 10 per cent. of the charge—which must now and then be removed, along with the ashes, and thrown into a water-sealed ashpit. The residue can, of course, be fed again into the producer together with the charges, after the ashes have been separated from it.

Even if the advantages gained by not being obliged to use a special and expensive reduction-fuel, and of carrying out the whole process in one and the same producer, are in themselves worthy of attention, still it must be urged against the construction in question that the

above-mentioned coal-residue, whether it is used for working the producer or not, still causes a certain amount of trouble. There are several power-stations working regularly which are provided with producers on this system. Amongst them, the central power-station belonging to the Montezuma Copper Co. in Nacoxari (Mexico)<sup>1</sup> deserves

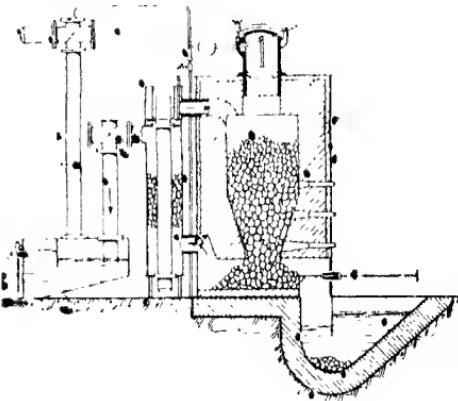


Fig. 2.

special mention. The fuel there consists of oak-refuse containing about 20 per cent. of water. The following figures deserve to be mentioned as averages of efficiency from a test lasting 120 hours. The effective heating value of the gas was found to be 117 B.T.U. per cubic foot (at 11.7 lbs. and 32° F.), with 15.5 per cent. of carbon dioxide. The consumption of fuel amounted to 2.62 lbs. per electric H.P. per hour, to which must be added 0.11 lb. of coke for firing.

*IV. Procedure in using double-zone producer, wherewith the air is conveyed to the producer both from above and below, while the gas is taken out about the middle of the producer.*

The producers belonging to this class can, with reason, be described as the result of the efforts made by certain designers to obtain simple

<sup>1</sup> The producers are on Loomis-Pettibone's system. They were manufactured by the Power and Mining Machinery Co., Milwaukee, Wis., U.S.A. (cf. p. 100).

and cheap apparatus. Thus, in this case too, it was desired to carry out the gasification, if possible, in a single furnace, and to let the products of distillation be carried onwards by a current of air through incandescent coal in order to be burned there. But the combustion of the distilled fuel was to take place more completely and reliably than by the method of procedure just mentioned (down-draught producers), for which reason *combustion on an ordinary grate was chosen for the distilled fuel*, but, on the other hand, *transformation into permanent gases within an extra zone of combustion, simultaneously with the admission of air, was adopted for the products of distillation*.

French and German designers have made important contributions towards the introduction and perfecting of these semi-water gas-producers too. Ever since the year 1890, when a Frenchman, *Dauber*, took out a patent for a producer—which, it is true, was supplied with air at three places, but which, in its method of producing gas, agreed in the main with the producers now about to be described—much thought and many expensive experiments have succeeded each other, the object being to construct a producer with double combustion-zones for bituminous fuel, which would work with perfect reliability.

Although the outlines of the method of procedure have already been given in the preceding pages, and although, strictly speaking, it does not belong to this chapter to treat of such constructions, it may, however, be of some use to first of all describe a producer with double combustion-zones, the *Deutz* new *lignite producer*, for example, in order thereby more clearly to illustrate the process of gasification.

The square furnace of such a producer (fig. 32) is, as usual, bounded at the bottom by a grate with an ashpit beneath it, from which the combustion-air is conveyed to the distilled fuel. Above, there is the *secondary air inlet*, and, in about the middle of the producer, the *gas-outlet*. When the engine is at work, a vacuum arises in the producer, the immediate consequence of which is, that air streams in, both at the bottom and at the top, thereby forming *an upper and a lower combustion-zone*. After every charging, the volatile ingredients are driven out of the raw fuel by the action of heat coming from the incandescent, already distilled coal lying beneath. These products go with the current of air through the upper zone of combustion, where their transformation into permanent gases takes place. Simultaneously there is consumed up here, and under the action of air, a part of the fuel which was just distilled. The heat which is developed during this process goes to supply the heat which is needed for the gasification and the transformation of the said products. The distilled fuel (coke) sinks gradually downwards and is gasified in the way already described, in the lower part of the producer. Both the streams of gas mix with each other in the gas-outlet, from out of which streams a producer-gas which is nearly altogether free from tar. If the percentage of moisture of the fuel is low, the gas will be poor in hydrogen, and in that case the combustion-air must, in some way or another, be mixed with steam. The lower part of the producer then

behaves, in respect to the gasification, exactly like an ordinary anthraeite producer. The firms of Koerting and Pintsch, and others, build producers for lignite and peat on the same principles.

Of the four methods mentioned, the first and the last are those that have come most into use, as *producers with return of tar-gases to the combustion-zone* have been successfully used for the gasification of peat and certain kinds of coal. *Producers with double combustion*, on the other hand, have been principally used for the production of producer-gas out of lignite briquettes.

The methods now described are not the only ones, however, that have been devised and employed. There are several others, but they can be used with advantage only under certain circumstances, and want of space prevents any description of them being given.

A producer which is charged with bituminous fuel may likewise be provided with ingenious devices for the rational transformation of the tar-products, or for preventing the proportion of water from interfering with the working; these means, however, cannot prevent the production of poor gas, if, as in the case of certain kinds of coal, the fuel begins to cake quickly, or if the coal begins to give off a great amount of liquid clinker, for, in such a case, the working of the producer is, so to say, entirely disarranged. Thus it might happen that the tar-vapours, together with the steam, pass undecomposed through the canals in the caked fuel; the purified gas becomes poor in heat and, unfortunately, is obtained in insufficient quantities; the combustion-air meets with great resistance within the producer, etc.

Amongst the improvements in gas-producers, intended to remedy these faults, there deserves to be mentioned the *Ludwig Mond* method of so greatly lowering the temperature in the producer, by means of a copious supply of steam, that ordinary clinker-forming coal can be gasified without difficulty. The steam which is blown in can amount to as much as about 2.5 times the weight of the coal. It is partly passed off without being decomposed, thereby causing, it is true, a considerable loss of heat. In experiments carried out by *Humphrey* with a plant on Mond's system, the total efficiency amounted only to 61 per cent., when the necessary amount of steam was generated by means of extra fuel, and when the fuel was also taken into account which was used for running the pumps and fans.

The lower economy of such plants, however, is usually improved by utilising the ammonia which, in the form of ammonium sulphate, is got from the nitrogen of the coal. The distillation of the gas from the fuel in a *Mond* producer takes place at so low a temperature, that the greater part of the ammonia which is driven off escapes undecomposed, along with the producer-gas. The tar-products, on the other hand, *Mond* endeavours to decompose in the producer.

During the last few years, *Dr A. Krantz*, in collaboration with

Dr. Caro, has succeeded in gasifying peat in a Mond producer, in which experiments it was calculated that 70-75 per cent. of the nitrogen of the fuel left the producer in the shape of ammonia. The peat used contained up to 50 per cent. water.

In the Mond gas plant, the gas, almost tar-free and copiously mingled with steam, is led to the *counter-stream condenser*, whose system of pipes it flows through, at the same time giving off heat to the mixture of air and steam which is driven along through the apparatus under pressure. The gas is then introduced into the *cleaning apparatus*, where it comes into intimate connection with the water (which is whirled into foam by means of two paddle-wheels in the apparatus), and, after being washed, it is led into the *acid-tower*, the interior of which is covered with lead and is also partly filled with brick. A solution of ammonium sulphate, with an excess of sulphuric acid, is made to run in a thin stream down into the tower, during which process the ammonia in the gas combines with the sulphuric acid to form fresh quantities of ammonium sulphate. Of the enriched solution which is collected at the bottom, a certain amount of sulphate is utilised, while the remainder is pumped up to the upper part of the tower, in order to be used again after receiving additional sulphuric acid. After having been further washed, the gas, after passing the *sawdust purifier*, is finally led to the gas-engines.

At a works at Warrington there was obtained gas of the following composition:—

|                 |                 |      |                  |
|-----------------|-----------------|------|------------------|
| Carbon dioxide  | CO <sub>2</sub> | 16.3 | volume per cent. |
| Carbon monoxide | CO              | 10.2 | " "              |
| Hydrogen        | H               | 26.1 | " "              |
| Methane         | CH <sub>4</sub> | 2.5  | " "              |
| Nitrogen        | N               | 44.6 | " "              |

For 1 lb. coal, with an effective heating value of 13,000 B.T.U. per lb., and 1.3 per cent. nitrogen, the yield of gas was 70.8 cubic feet (at 14.7 lbs. and 32° F.), and of sulphate 0.044 lb. As the salt contains about 24 per cent. of ammonia, there was thus obtained about 1 lb. of ammonia per 100 lbs. gasified coal.

Amongst those who have long busied themselves with the construction of gas plants for power purposes, where the operation is, at the same time, based upon the utilisation of certain chemical-technical products, we may mention the firm of Pintsch. In this firm's producer for the purpose mentioned, the fuel is usually gasified without the transformation of the tar-vapours; in this manner, tar is obtained in addition to the sulphate. The high first cost of such a plant contributes, however, in some measure to make the whole of the combined working dearer, for which reason an economically favourable result can only be expected in the case of large installations.

The often considerable percentage of water in the case of certain bituminous fuels, such as peat and lignite, renders it much more difficult to retain a temperature in the producer which will be suffi-

ciently high under all conditions. The risk is thereby run, first, that the generation of gas, especially at light loads, may stop, and also that the quality of the gas may deteriorate in a very high degree, viz. so that the percentage of carbon dioxide easily becomes too high, and tar-products in larger quantities are found in the gas. There is, of course, a difference in these respects between the different types of producers.

First, as regards producers with double zones of combustion, in which the distillation of the fuel and transformation of the tar-products into permanent gases take place through the action of heat from an upper zone of combustion. It can easily be seen that specially great difficulties will present themselves in the case of such an arrangement, not only in regard to obtaining a proper temperature through this zone, but also as regards the retention of the zone in its proper position. When a fuel with a large percentage of water is charged into such a producer (cf. fig. 32), the fire seems, so to say, to be quenched for a moment in the upper zone; the fresh fuel is distilled too slowly, and does not catch fire sufficiently quickly, as the flame in the fuel can only force its way upwards with a velocity which is less than that with which the distilled fuel sinks. *The zone of combustion, therefore, slowly sinks*, which creates a growing risk of disturbing the order of gasification in the upper part of the producer, in proportion as the distance between the zone and the gas-outlet is diminished. The comparatively small development of heat in the secondary combustion zone of the producer does not seem to be sufficient both to distil and to gasify moister kinds of fuel, and—from experiments made with Dautz' producer—the proportion of water in lignite and peat should not exceed 20 per cent., if inconveniences, such as those just mentioned, are to be avoided.

A better result can be counted on, however, with respect to the gasification of fuel containing a large percentage of water, if, in the upper part of a producer with double zones of combustion, there is built a retort-like container in which the fuel is dried before it glides down through the upper zone. The same may be said of the use of drying apparatus. Both methods are employed, especially in the case of raw peat as fuel.

In producers working with return of tarry gases to the combustion-zone, the distillation usually takes place only by the action of heat from the escaping gases which, on their passage, stream over the fuel-container (cf. fig. 30). The transformation of the products of distillation takes place, on the other hand, in the combustion-zone itself, with its great supply of heat. Experience has shown, however, that the gasification of peat or lignite with a high percentage of moisture is, in such a producer, attended by considerable difficulties, resulting from the heat necessary for distillation being, thanks to the great latent heat of steam, supplied with difficulty by the free heat of the escaping gas, especially as effective measures for facilitating the passage of the heat from the gas to the fuel are, for practical reasons,

usually not employed. The consequence is, that a part of the fuel leaves the container undistilled, and sinks down towards the reduction and combustion zones in the distilled fuel. In this process, the moisture evaporates in zones which are so deep that in these places the secondary exhaustion, if it is not powerful enough, can easily be overcome by the primary one, causing a loss of heat through the undecomposed steam which passes off direct with the gas. Under such circumstances, the gas, too, will naturally contain a considerable amount of tar consisting partly of heavier hydrocarbons, which were driven out of the fuel too late, and have therefore muted themselves to the other gases in an unaltered state, and partly, too, of hydrocarbons which, it is true, have been drawn off in the right way and carried into the combustion zone, where, however, the low temperature rendered their complete transformation into permanent gases an impossibility.

A method of driving up the temperature in the producer consists of mixing the peat with strongly heat-producing fuels, such as anthracite and coke. This method of procedure must, however, be regarded more as a measure of necessity which should be avoided as soon as possible, as the procuring and management of two fuels always causes some inconvenience in addition to which, economic reasons often prevent the use of such additional fuel.

Another method of procedure for the gasification of peat with a high percentage of water is employed by the firm of *Koerting*. The drying and distillation of the fresh fuel takes place here, as in the case of a producer with double combustion, by the help of heat produced through the complete combustion of a part of the raw peat in a secondary air stream, all of which takes place in the upper part of the producer, with the assistance of certain arrangements which, in a high degree, help the transference of the heat to the fresh fuel. The producer, which also works with secondary exhaustion of the products of distillation, is described in more detail on page 93.

If, thus, on the one side, a considerable percentage of moisture in the bituminous fuels is a hindrance to their continuous gasification, it gives, on the other hand, as a rule, the advantage of a simplification of the gas-plant employed, viz. that in these cases one can usually dispense with the use of a special vaporiser. This usually holds good for fuels with more than 20 per cent. of moisture.

With about 10 per cent. of moisture in the peat, we have probably already passed the limits of moisture allowed by the working and economy in general. Peat with a higher percentage of water behaves, especially if it is much broken up too, like a pulpy mass, which, when in the producer, must often be opened up in order to admit of the easier passage of the combustion-air; this becomes in the long run not only troublesome, but uneconomical.

After having mentioned all the difficulties in the way of obtaining a perfectly equable gasification of bituminous fuel in producers, some information respecting the occurrence of peat, its preparation as a fuel,

and its chief qualities, ought to be of special interest, as it would seem that the utilisation of peat-bogs in different countries is about to become of great national importance. The following information and descriptions chiefly have regard to the *utilisation of the peat for power purposes*, and not to a future employment of this fuel, probably on a far larger scale, for ordinary heating purposes and for metallurgical use, an employment for which we have every reason to entertain the greatest hopes. The utilisation of peat for the first-named purpose has, however, made rapid progress during the last few years, and especially in Sweden, the first power-station driven by peat-gas engines, and situated at *Söderby*, Sweden, which was, in fact, the first such station ever erected, having started early in the year 1901, while at present the total number of such plants in Sweden already existing is at least ten, with a total power of more than 2000 B.H.P.

*Peat* (or *turf*) is obtained from the so-called peat-logs, or mosses, which, in Sweden, are supposed to occupy more than 12 per cent. of the total area of the country. It has been approximately estimated that, basing our calculations on the present consumption of coal in the country, the mosses of Sweden should be sufficient to supply its demand for fuel for the next thousand years.

It does not lie within the province of this work to give a detailed description of the different methods employed for taking up and drying the peat. We shall here just mention briefly that, for taking up and preparing *peat fuel* on a large scale, advantageous use is made of *peat-cutting machines*, which dig up the peat and prepare it in various ways. A distinction is made in this respect between the preparation of peat by means of the addition of water, so as to obtain a pulpy mass, which is poured out on to the ground in order to be air-dried, and the preparation of pressed peat, by which is meant the laying out of the peat in rows. In this method of preparation the mass is usually prepared without the addition of water, and the moulding of the mass takes place with the help of nozzles. The rows are then taken up in bits on so-called *peat-boards*, in order to allow of the peat being more easily transported into the field to be dried. There is also the preparation of *spade-cut peat*, which takes place by the very simple method of cutting the peat out of the bog and at once putting it out in the air to dry. Spade-cut peat is either taken up by hand or else with the help of simple machines. Spade-cutting the peat is, however, dearer than machine-cutting it, and also requires a considerable number of hands, whom it is not always so easy to get together during the summer months, when other work is going on. This seems to be the case in Sweden, at least.

The drying in the air of the wet peat-mass takes varying lengths of time, dependent on whether it is desired to have ordinary *peat fuel* or *peat briquettes*. Thus good air-dried peat fuel ought not to contain more than 25 per cent. of moisture, while bog-peat for peat briquettes may have up to 50 per cent. of water. With a 25 per

cent. moisture, the average composition of peat is stated to be as follows:—

|                    | Swedish.         | Irish.           |
|--------------------|------------------|------------------|
| Carbon . . . . .   | C 11.17 per cent | 44.25 per cent.  |
| Hydrogen . . . . . | H 4.20 ..        | 4.50 ..          |
| Oxygen . . . . .   | O 21.94 ..       | 22.50 ..         |
| Nitrogen . . . . . | N 1.59 ..        | 0.91 ..          |
| Sulphur . . . . .  | S 0.32 ..        | " ..             |
| Ash . . . . .      | 2.78 ..          | 3.00 ..          |
| Moisture . . . . . | 25.00 ..         | 25.00 ..         |
|                    | 100.00 per cent. | 100.19 per cent. |

Perfectly dry Swedish peat has an effective heating value of 9730 B.T.U. per lb., figures which have been obtained as the average value in tests made by *G. v. Hedenstrom*, chemist to the Swedish State railways. General samples were taken of peat from sixteen different Swedish peat-works. With a "normal" proportion of moisture of the fuel amounting to 25 per cent., the heating value was 6610 B.T.U. per lb.

In general, when making our calculations, we may base our estimations on the above composition, and an effective heating value of 6600 B.T.U. per lb., in the case of machine-cut peat of normal percentage, and taken from the peat-works of *Central Sweden*. One exception must, however, be made in the case of *Gotland* peat, viz. in respect to the percentage of ash, which, in this case, is usually more than 8 per cent. Peat from the province of *Norrbotten*, on the other hand, usually contains a smaller amount of ash than the kind just mentioned; the percentage, however, is scarcely ever less than 4 per cent. If we compare Swedish peats with foreign, we find that, in respect to ash, the percentage is generally less in the case of the Swedish material.

Ordinary fuel-peat possesses several qualities which make it a valuable fuel for producers, amongst which is, that the percentage of moisture of the fuel, as was already shown, makes it possible, as a rule, to omit the vapouriser with its accessories, thereby lessening the cost of construction and upkeep. In addition to this, the fuel, on being heated, *does not give off any liquid clinker*, but, at the very most, only shows a tendency to sinter together in loose lumps, which easily fall to pieces. There is, therefore, no reason for the occurrence of any injurious resistance in the producer, and so the gasification can, with advantage, be carried out in accordance with the simple suction-gas system. The difficulties which ordinarily occur in attempts to gasify air-dried peat economically, may be summarised as follows:—

The great and very variable percentage of moisture in the fuel, together with its low heating value, place great hindrances in the way of attaining and, above all, of keeping up a sufficiently great heat in the producer. The inconveniences which are the immediate con-

sequence of this have already been mentioned (p. 31), with special regard to types of producers in use, together with a number of improvements in the construction of peat-gas producers intended to remedy these defects.

It can be considered that it is making a great demand on a producer to gasify peat with as much as 40 per cent. moisture, easily and economically as this is a very difficult task to carry out, but it is probably not an exaggerated one if respect be paid to the condition of things in Sweden especially. The preparation of peat is, as we have mentioned, dependent on the drying in the air, for which reason a short or bad drying summer might make it impossible to get a peat with a lower percentage of moisture than the one just stated. This is especially so with the manufacture of peat fuel on a small scale, when the fuel, as a rule, is obtained from bogs belonging to the station and in its neighbourhood. It is, of course, not impossible even here to reduce the percentage of water by means of suitable arrangements, but, from economical reasons, it would hardly pay. A better solution of the *peat-power problem* lies in the construction of a producer in which special regard is paid to the very high percentage of water which sometimes occurs in the peat.

Another inconvenience with peat fuel is the ease with which it falls into small pieces on crushing, which must necessarily precede the introduction of the fuel into the producer. As a rule, the fuel consists of pressed peat in long pieces of rectangular section, which are broken into smaller pieces varying in size from about 2 inches down to peat-dust. The peat-dust can, of course, be separated from the fuel by screening, but the amount of refuse which arises is often very large and also difficult of utilisation economically. As we have seen in the preceding pages, a high percentage of dust in the fuel often has a disturbing action upon the uniformity of the gasification, for which reason, in general, a producer which can at once treat the crushed, unsorted peat ought to be considered as the best.

Finally, peat, compared with coal, is slow in combustion—a quality which further renders the gasification of this fuel difficult. A piece of pressed peat is compact, the fracture presenting an earthy appearance. When such a piece of peat burns, combustion takes place only on the surface without cracks arising or the peat falling into small pieces, as the case is when ordinary coals burn. This quality of the fuel is, however, often a hindrance to its use in producers with a combustion zone situated in the upper part of the fuel-column which, during gasification, tends to move downwards if the fuel which has been put in burns too slowly. The peat, however, remains incandescent a long time, which greatly facilitates the blowing up of the producer. This property makes it even possible to let the blowing up take place by means of natural draught, which contributes to simplify the working of a peat-gas plant.

Amongst the examinations of the gas made of late years we may, to begin with, give the results of those carried out in October 1906,

at *Skabersjö power-station* by *G. v. Heidenstam*, which are specially interesting from the point of view of gasification, as the analyses also embrace the gas, such as it was obtained before the producer got into normal operation. (For a more detailed account, see p. 21.)

TABLE VI.

| No.   | 1      | 2    | 3    | 4    | 5    | 6    | 8      | 9     | 10   | Average<br>of Nos.<br>8-10. |       |  |
|---|--------|------|------|------|------|------|--------|-------|------|-----------------------------|-------|--|
| Date  | 8 Oct. |      |      |      |      |      | 9 Oct. |       |      |                             |       |  |
| Hour  | 11.15  | 1.15 | 2    | 3    | 4    | 9.40 | 10.40  | 12.45 | 2    | 3                           | 10.40 |  |
|   | a.m.   | p.m. | p.m. | p.m. | p.m. | a.m. | a.m.   | p.m.  | p.m. | p.m.                        |       |  |
| Carbon dioxide,<br>CO <sub>2</sub>  | 10.5   | 10.4 | 9.4  | 10.6 | 9.8  | 9.0  | 9.2    | 9.3   | 9.7  | 9.6                         | 9.36  |  |
| Carbon mon-<br>oxide, CO  | 17.2   | 18.5 | 18.8 | 17.0 | 20.0 | 21.5 | 20.3   | 19.9  | 20.2 | 20.1                        | 20.40 |  |
| Oxygen O  | 0.9    | 0.8  | 1.3  | 0.9  | 0.0  | 0.0  | 0.0    | 0.1   | 0.0  | 0.0                         | 0.92  |  |
| Heavy hydro-<br>carbons   | 2.8    | 2.1  | 1.9  | 0.4  | 0.2  | 0.3  | 0.4    | 0.3   | 0.4  | 0.3                         | 0.34  |  |
| Methane CH <sub>4</sub>   | 5.2    | 6.0  | 5.5  | 6.0  | 5.5  | 5.7  | 5.2    | 6.2   | 6.5  | 5.3                         | 5.78  |  |
| Hydrogen H  | 6.8    | 5.8  | 6.5  | 5.3  | 6.5  | 6.3  | 6.8    | 6.0   | 5.3  | 6.7                         | 6.22  |  |
| Nitrogen N  | 55.6   | 56.6 | 56.6 | 58.8 | 58.0 | 57.2 | 58.1   | 58.2  | 57.9 | 58.0                        | 57.83 |  |
| Calculated eff.<br>heating-value<br>per cubic ft.<br>(at 14.7 lbs.<br>and 32° F.)<br>B.T.U. | 163    | 162  | 160  | 133  | 136  | 143  | 137    | 142   | 145  | 136                         | 141   |  |

The values given in the table are expressed in volume-percentage. The gas thus contains, on an average, about 32 per cent. of combustible substance, and the effective heating value amounts to 141 B.T.U. per cubic foot (at 14.7 lbs. and 32° F.). Normal working conditions can be said to have commenced about 1 p.m., to judge from the percentage of carbon monoxide which, after that time, keeps very even. In order to completely consume 1 cubic foot of gas of the above composition, there is required about 1.2 cubic ft. air.

The peat fuel gasified during the test had the following composition:—

|                       |       |           |
|-----------------------|-------|-----------|
| Combustible substance | 61.23 | per cent. |
| Ash                   | 6.49  | "         |
| Moisture              | 32.30 | "         |

The effective heating value amounted to 5364 B.T.U. per lb., original sample; calculated on moisture-free sample, 1 lb. of peat gives 8937 B.T.U. per lb.

Of great interest, too, is a test made in 1901 at a power plant at the *Burangsberg Mine*, where the peat was of the following composition:—

|                       |       |           |
|-----------------------|-------|-----------|
| Combustible substance | 51.91 | per cent. |
| Ash                   | 5.38  | "         |
| Moisture              | 39.71 | "         |

while, in a moisture-free sample, the peat contained 9251 B.T.U. per lb., corresponding to 5150 B.T.U. in its original condition. In spite of the high percentage of moisture, excellent results were obtained in economical respects.

Another series of tests from the above-mentioned Skabersjo works may be given, especially as, by this series, the efficiency of the producer was determined as well. The test was carried out at the close of 1905, and the fuel analyses showed that the peat contained 27-28 per cent. moisture and 6 per cent. ash. The effective heating value of the fuel amounted to 5760 B.T.U. per lb., and the gas got from it was of the following composition:—

|                 |                 |      |           |
|-----------------|-----------------|------|-----------|
| Carbon dioxide  | CO <sub>2</sub> | 11.4 | per cent. |
| Carbon monoxide | CO              | 16.8 | "         |
| Methane         | CH <sub>4</sub> | 1.8  | "         |
| Hydrogen        | H               | 8.3  | "         |
| Nitrogen        | N               | 58.7 | per cent. |

In the four tests made, the efficiency of the producer varied between 71.5 and 78 per cent., with an average of 74.5 per cent. The tests were carried out during normal operation.

Under present conditions, peat-gas plants can probably be worked with any profit only in the neighbourhood of peat-bogs, as the freight for the peat, which takes up very much room, is too high to allow of this fuel competing in price with coal, at works lying at any great distance from the bogs. Whether, in Sweden, peat can ever compete in price with anthracite or coke at places situated at a distance from the peat-bog, for example at the towns along the coast, where the fuel is transported in concentrated form and, thus, at reduced rates, to the place where it is to be used, is difficult to foretell, for the manufacture of peat briquettes in Sweden is at present still in an experimental stage, and, from the many investigations which have been made in the matter, it seems as if the peat briquettes will cost from 9s.-12s. per ton at the works. The effective heating value of such peat usually varies between 7600-11,100 B.T.U. per lb.<sup>1</sup> Machine-cut peat prepared in the usual way costs, on the other hand, only

<sup>1</sup> The latter figure refers to peat briquettes manufactured on the wet-carbonising method, also known as the Ljungson-Ekenberg process.

4s. 6d.-7s. per ton. The heating value is, it is true, lower in the case of peat briquettes, viz. 6600 B.T.U., when there is 25 per cent. of moisture. On the other hand 1 cubic foot of the former fuel weighs 50-56 lbs. and more, while the weight per cubic foot for machine-cut peat amounts, on the average, to 22 lbs. Peat briquettes have many other advantages over ordinary peat fuel, such as great power of resistance to outer damage, greater uniformity in composition, size, etc., all of which contribute to a most effective and economical gasification of the fuel, and so it would seem as if a competition with anthracite is not an impossibility, especially as this latter fuel shows a tendency to increase in price from year to year, and the problem of the employment of ordinary coal for gas-engine plants has not yet been solved in a satisfactory manner.

*Lignite*.—This fuel, which, in regard to its composition, lies between coal and peat, is already being used to a great extent at several places for power purposes. As is the case with peat, lignite is of such low grade that its employment, as a rule, must be considered as confined to the place where it is obtained. An exception can be made in the case of briquetted lignite. Such briquettes, which are very much used in Germany and Austria-Hungary, are, on account of their uniform size and relatively small percentage of moisture, very suitable for use in producers which have been constructed with special regard to the percentage of bituminous ingredients of the fuel.

Some analyses of American lignite (perfectly dried fuel) are given here below<sup>1</sup>:-

| Lignite from   |                             |                             |  |
|--|-----------------------------|-----------------------------|--|
|  | Alameda Co.,<br>California. | Stark Co.,<br>North Dakota. |  |
|  | Per cent.                   | Per cent.                   |  |
| Carbon   | 63                          | 39.5                        |  |
| Hydrogen   | 6.1                         | 6.2                         |  |
| Oxygen   | 27.6                        | 38.9                        |  |
| Nitrogen   | 0.7                         | 0.5                         |  |
| Sulphur  | 3.0                         | 3.5                         |  |
| Ash  | 15.5                        | 11.4                        |  |
| Moisture in air-dried fuel                                   | 100.0                       | 100.0                       |  |
| Eff. heating value of perfectly dried fuel in B.T.U. per lb. | 18.5                        | 32.6                        |  |
|  | 10,020                      | 10,800                      |  |

Respecting the employment of bituminous fuel in producers, it may be seen from the above that much remains to be thought out and improved in this branch, both in respect to the methods for the transformation of the tar-vapours into permanent gases and also as regards the maintenance of an undisturbed and equable generation of gas at all loads.

(c) **Natural Gas.**

Natural gas is found in the oil districts of the United States, notably in Pennsylvania, Ohio, and Indiana. It is a product of decomposed vegetation, and can be reached by drilling wells. Such gas can be considered as an ideal fuel, being very rich, and requiring no cleaning. Some analyses of natural gas from different localities are given below:—

TABLE VII.

| Constituents of the Gas.   | Locality.         |                |                   |                 |      |
|--|-------------------|----------------|-------------------|-----------------|------|
|  | Pittsburg,<br>Pa. | Findley,<br>O. | Anderson,<br>Ind. | Muncie,<br>Ind. |      |
| Per cent.  | Per cent.         | Per cent.      | Per cent.         |                 |      |
| Carbon dioxide   | CO <sub>2</sub>   | 0.6            | 0.5               | 0.3             | 0.4  |
| Carbon monoxide  | CO                | 0.6            | 0.5               | 0.7             | 0.4  |
| Oxygen   | O                 | 0.8            | 0.3               | 0.1             | 0.3  |
| Heavy hydrocarbons   |                   | 1.0            | 0.3               | 0.5             | 0.2  |
| Methane  | CH <sub>4</sub>   | 67.6           | 92.6              | 93.1            | 92.7 |
| Hydrogen   | H                 | 22.0           | 2.2               | 2.0             | 2.5  |
| Nitrogen   | N                 | 3.0            | 3.6               | 3.0             | 3.5  |
| Effective heating value per<br>cub. ft. (at 14.7 lbs. and<br>32° F.) in B.T.U. |                   | 745            | 930               | 935             | 930  |

The amount of air theoretically required for complete combustion will range from 7.5-9.5 cubic feet air per cubic foot gas.

(d) **Blast-Furnace Gas.**

From a thermal point of view, a blast-furnace may be considered as an air-gas producer in which combustible gas and a valuable by-product, pig-iron, are produced with so favourable a result that, after subtracting all the working expenses from the money-value of the by-product, a considerable profit remains.

There is a certain resemblance, too, between the composition of

air-gas (Siemens producer-gas) and blast-furnace gas, viz. as regards the kinds of the component parts, even if not with respect to quantity. The cause of this is partly to be found in the charges of the blast-furnace, which, in composition, are different from those of the ordinary producer, whether these consist of distilled or undistilled fuel.

As is well known, a blast-furnace is charged with *ore* and *limestone* as well as the *fuel*, and the ore is required by the carbon monoxide formed over and around the tuyères, simultaneously with the formation of carbon dioxide. In addition to this, carbon dioxide is driven out of the limestone and sometimes out of the *ore*, too, which carbon dioxide, together with the other, is partly reduced to carbon monoxide, and partly escapes unreduced. Blast-furnace gas thereby becomes richer in carbon dioxide than producer-gas.

In respect of the percentages of hydrogen, however, the two gases resemble each other; both being comparatively poor, as the blowing, in both cases, takes place with dry blast. Compared with coke blast-furnace gas, charcoal furnaces give a gas richer in hydrogen and marsh-gas or methane, a fact which satisfactorily explains the considerable difference in their effective heating value.

On account of its high percentage of carbon dioxide, blast-furnace gas is usually somewhat poorer in carbon monoxide than air-gas is; the difference is, however, not great.

Finally, amongst the gaseous components of blast-furnace gas may be mentioned *steam*, derived mainly from the moisture in the material forming the charge; the proportion is sometimes very great, often exceeding 10 per cent.

The composition and heating value of blast-furnace gas varies, it will easily be understood, according to the character of the fuel and the other components of the charge, the regularity of the working, the size of the furnace, etc. The difference in the composition of the gas in the case of Swedish charcoal blast-furnaces and coke furnaces is clearly shown by the following tables. Table VIII. gives the result of *Tamm's* analyses of gases from 28 Swedish charcoal blast-furnaces;

TABLE VIII.  
*Swedish Charcoal Blast-Furnaces.*

| Vol. per cent. | Carbon dioxide,<br>$\text{CO}_2$ | Carbon monoxide,<br>$\text{CO}$ | Hydrogen,<br>$\text{H} + \text{CH}_4$ | Nitrogen,<br>N |
|----------------|----------------------------------|---------------------------------|---------------------------------------|----------------|
| Maximum        | 17.5                             | 29.5                            | 12.7                                  | 59.1           |
| Minimum        | 6.6                              | 20.5                            | 3.0                                   | 51.0           |
| Average        | 11.9                             | 25.9                            | 5.2                                   | 57.0           |

Table IX., on the other hand, shows the composition of coke blast-furnace gas, from analyses by *Leclerc*; both tables show within what limits the amounts of the different components usually occur in the gas.

TABLE IX.  
Coke Blast-Furnaces.

| Vol. per cent. | Carbon dioxide, $\text{CO}_2$ | Carbon monoxide, $\text{CO}$ | Hydrogen, H. | Methane, $\text{CH}_4$ | Nitrogen, N |
|----------------|-------------------------------|------------------------------|--------------|------------------------|-------------|
| Maximum        | 18                            | 32                           | 6            | 6                      | 65          |
| Minimum        | 6                             | 20                           | 1            | 2                      | 55          |
| Average        | 12                            | 24                           | 2            | 2                      | 60          |

From among the analyses lately made of the composition of blast-furnace gas from Swedish works, we give here *E. Hubendick's* results from samples of gas examined in 1900, and others taken in the year 1902, at *Nyrhytte Works*. The results are given together in Table X., where we also find *L. Rinman's* analyses from *Dalkarlsbyttan Works*, carried out in 1876. The values obtained in these last-named investigations differ very considerably, however, from those of the former, as the effective heating value of Dalkarlsbyttan gas only amounted to 96 B.T.U. per cubic foot, thus being more than 35 per cent. less than *Boxholme* gas. The values from these two works are typical, and will probably for some long time be regarded as the limits within which the effective heating values of blast-furnace gas from Swedish charcoal furnaces can vary.

Thus, on an average, the effective heating value, omitting Rinman's value, amounts to 137 B.T.U. per cubic foot, or, including this value, to 131 B.T.U. per cubic foot.

From coke blast-furnaces we have several determinations of heating values, and amongst them those carried out by *Donkin*, *Meyer*, and *Hubert*. Donkin obtained at English and Scotch blast-furnaces an effective heating value of the gas equal to 200 B.T.U. per cubic foot. Meyer obtained as the average of 5 samples of blast-furnace gas from *Differdingen, Germany*, 106 B.T.U. per cubic foot; Hubert determined the effective heating value of 12 samples of gas from the blast-furnaces of *Scraing, Belgium*, to be 112 B.T.U. per cubic foot—all figures relating to a pressure of 14.7 lbs. per square inch and a temperature of 32° F.

As may be seen, the differences in the heating values of blast-furnace gas from Swedish charcoal furnaces, and of gas obtained from coke blast-furnaces, are fairly considerable, and, as will be remembered, we have already mentioned the cause of this.

As the need of air for the complete combustion of fuel generally increases almost proportionally with its effective heating value, it is

TABLE X.

clear that blast-furnace gas from Swedish charcoal furnaces should demand comparatively more air on combustion than, for example, gas from coke furnaces, which, when dry and purified, needs about 0.76 cubic foot per cubic foot gas.

In Table X. the necessary amount of combustion-air,  $L$  cubic feet per cubic foot dry and purified gas, has also been calculated with the assistance of previous reports respecting the gas at Swedish blast-furnaces, in order to ascertain the above-mentioned proportion, the ratio  $L : W$ . As an average there was obtained 0.00773, which, with the exception of the value for the Dalkarlsbyttan Works, differs little from the other values, for which reason, in calculations, and when analyses cannot be procured of the gas in question, it seems as if we might determine the theoretically necessary amount of combustion-air per cubic foot of blast-furnace gas from the formulae—

$$L = 0.00773 W \text{ for charcoal furnaces,}$$

$$L = 0.00738 W \text{ for coke furnaces,}$$

on the supposition that the effective heating-value,  $W$ , measured in B.T.U. per cubic foot at 11.7 lbs. and 32° F. is known. The greatest divergence is obtained for the gas from Dalkarlsbyttan, viz. nearly 6 per cent. The last column of the table gives the values of the weight per cubic foot gas, where the great influence of hydrogen and methane can clearly be distinguished.

What was said above about blast-furnace gas had respect to its gaseous components. The gas, when it leaves the furnace, however, carries with it more or less finely divided solid impurities, *dust*, in larger or smaller quantities, the reduction of which to a percentage allowed by the working of the gas-engine, without making the cost of construction for the necessary cleaning apparatus altogether too high, is a problem the proper solution of which has already proved to be of the very greatest importance for the economical utilisation of blast-furnace gas in gas-engines.

Ever since the first employment of blast-furnace gas-engines, the necessity has been recognised of well purifying the gas from mechanical impurities, which would otherwise injure the internal working parts of the engine. Later experience has shown, however, that the cleaning of the gas should also necessarily be extended to the removal, as far as possible, of the steam accompanying the gas, partly in order to avoid irregularities in ignition and partly, too, because the separation of the dust from the gas within the engine is rendered more difficult on passing sharp edges of valves, and other delicate details of regulation, if the gas be dry. In moist gas which has been cooled before being led into the engine, the particles of dust are, on the contrary, coated with condensation water, and are thus heavier; the particles are therefore carried more easily out of the direction of the current and deposited in the neighbourhood of the places above mentioned. For an engine which works for a long period incessantly, such moist deposits of dust need not necessarily become the cause of

irregular working, as they do not hinder the movement of the valve gear in any noteworthy degree. If, on the other hand, the working is often stopped, the dust deposited becomes hard, thereby giving rise to great hindrances to the movement of the above-mentioned engine parts which might even make the next starting of the engine impossible. Other disturbances, again, can be caused by the dust burning fast together with the oil on badly cooled surfaces inside the cylinder: the thin coatings loosen a little from the inner surface, soon get hot, and thereby give rise to pre-ignitions. Too much lubrication also seems to facilitate the occurrence of such disturbances.

As is well known, the greatest amount of steam which a given quantity of gas can receive and retain depends on the temperature of the gas. The capacity also increases rapidly along with the temperature, and so the simplest method of obtaining the driest gas possible is to cool it as far as possible. The cooling also increases the maximum power and the thermal efficiency of the engine, this latter on account of the possibility of increasing the compression without causing any pre-ignitions, not to mention other advantages.

To summarise what has been said above, the conditions necessary for a thoroughly reliable and economical working with gas engines for blast-furnace gas are, that the gas shall be fed into the engine as *clean and as dry as possible*, and also *well cooled*.

Before the different methods of cleaning are *concreta* and discussed, we shall give an account of the origin and composition of the dust accompanying the gas, as well as of the requirements usually prescribed by the maker of the engine as to the purity of the gas, its freedom from moisture, and its degree of coolness.

The dust in blast-furnace gas is derived partly from the charges in the upper part of the furnace, and partly from the smelting and reduction zones. While the greater part of the former consists of coarse ore- and coal-powder, and as such can easily be separated from the gas by the help of "dust pockets" (see fig. 3), the removal of the latter is attended with far greater difficulties, as the fineness of this dust is usually so great that the particles can remain floating in the gas while passing through many hundred yards of piping. In Swedish blast-furnaces these mixtures consist of *powdered ore* (oxide of iron), *powdered charcoal*, *calcium carbonate*, and *silicates*.

As far as regards the amount of dust, it will be seen at once that the coke blast-furnaces which smelt more friable kinds of ore will give a gas with a larger percentage of dust than those charged with the more compact sort of ore. As a rule, the percentage of dust in the gas of coke blast-furnaces varies between 4-6 grammes per cubic metre,<sup>1</sup> (= 1.8-2.6 grains per cubic foot), after it has passed the dust-pockets, and then the impurities consist almost entirely of fine particles of dust. In Swedish charcoal furnaces are smelted the compacter kinds of ore,

<sup>1</sup> 0.34 grain per cubic foot is practically equivalent to 1 grammie per cubic metre.

and so the gas from such blast-furnaces is considerably cleaner than that from those just mentioned. According to *Hubendick's* experiments, the Swedish gas contains only 1.5-2.5 grammes of dust per cubic metre gas (=0.65-1.1 grains per cubic foot). The total percentage of dust varies, however, continually during the working, and is ~~usually~~ greatest immediately after a charge when the blast is admitted again.

The degree of purity of cleaned blast-furnace gas for motor purposes varies very much at different works, but still it appears as if the amount of dust at recently erected power-plants for coke gas lies between 0.015 and 0.043 grammes per cubic metre gas, except at a few works, where the purification is carried out to such a great degree that the percentage may fall to 0.001-0.005 gramme per cubic metre.

The manufacturers of gas-engines usually prescribe in their contracts, as a highest permissible amount of dust, 0.02 gramme per cubic metre gas.

In order to obtain the requisite purity of the gas, use is made of certain apparatus specially constructed for the purpose, by means of which the percentage of dust is gradually reduced to the prescribed figure: this is done, partly because the whole of the cleaning process ~~can only~~ with difficulty be carried out in a single apparatus, and also because gas of lesser purity is always used at the works for *heating of boilers*, *blast-heating*, and for *roasting ore*, etc. It may be mentioned that, at a number of works, a considerable saving in the working expenses of the steam-generation, the heating of the blast, etc., is made by cleaning the gas intended for these purposes more thoroughly. The coating of non-conductive dust, which would otherwise settle on the heating surfaces, has shown itself to be, in a very high degree, a hindrance to the conduction of heat; in addition to which, cleaning ~~must~~ often be undertaken, and thus, in the long run, becomes both expensive and troublesome. Nowadays, therefore, *the whole* of the amount of gas coming from the blast-furnaces is cleaned to a degree suitable for the purposes last mentioned—about 0.5 gramme of dust per cubic metre—while the more thorough cleaning for the purpose of being used as engine gas, is only applied to the remaining gas, after the boilers and various apparatus have got what they require.

The apparatus constructed for the cleaning and drying of blast-furnace gas present, on comparison, important differences, both as regards design and size, even if the amount of gas, the percentage of dust, and the demands that are made on the quality of the purified gas, happen to be the same. The various principles which have been followed in cleaning have had the further result that the apparatus at different works present very great variations.

The great interest nowadays evinced on the Continent in the use of blast-furnace gas in gas-engines has, however, brought about certain alterations for the better in this respect, too, as the manufacture of cleaning apparatus there is carried on as a speciality by several manufacturers of repute, and the consequence of this is a better utilisation of methods which had, a long time previous, been

employed at many private ironworks. In the arrangements of a modern cleaning apparatus for blast-furnace gas, greater uniformity has been introduced, however; this holds good especially for the more thorough cleaning which, nowadays, is everywhere carried out by means of machinery. It would occupy too much space to give a detailed description here of both older and modern cleaning apparatus, and so reference will only be made to a few of the latest machines for this purpose.

Dust-pockets are, in general, used for the removal of the coarser dust, together with a number of other apparatus constructed on the principle that heavy particles are thrown out of a gas-stream on passing sharp bends and projecting parts. Fig. 3 shows such a dust-separator of recent construction which does not require any further explanation. The apparatus just mentioned can be comprised under the title of "dry cleaners."

The more thorough cleaning is, on the other hand, usually best carried out in the wet way, by using scrubbers or rotary gas-washers for dust percentages down to about 0.5 grammes per cubic metre. For further preparation of gas suitable for the engine, containing between 0.015-0.03 grammes per cubic metre, it is impossible, as a rule, according to recent investigations, to do without the cleaning machines. In gas-washers the gas is at the same time cooled, in which process the accompanying steam is partly condensed, together with the larger or smaller quantity of steam formed out of the cleaning water at the cost of the free heat of the gas. At works which have not a very good supply of water, it is by these means possible to replace the cleaning water which has been lost through evaporation in the settling-tank.

The partial transformation of the cleaning water into steam by the heat of the gas, and the condensation of the steam in the colder remainder, which takes place immediately afterwards, are, on the contrary, of great importance, especially for the precipitation of the finer forms of dust. For gas-washing really aims at coating each particle of dust with a film of water, which makes the particle both larger and heavier; the particles can thereby not only more easily attach themselves to surfaces, but are more powerfully influenced by gravity and centrifugal force. In other words, "the seizing of the dust by water," and its separation from the gas in a moist state, are the chief objects of gas-washing. The coating of the particles with water cannot be imagined as taking place in a more perfect way than by the condensation of the steam accompanying the gas, as this steam everywhere surrounds the particles in an extremely finely divided

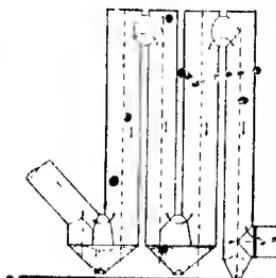


Fig. 3

state. In order to obtain an effective cleaning, it would seem as if the gas should be conveyed to the gas-washer at as high a temperature as possible; it can then, from what has already been shown, carry with it a comparatively larger amount of steam than when it is cold, in addition to the fact that the gas, by giving off some heat to the cleaning water, is further enriched with steam from this latter. The ease with which even the finest particles of dust allow themselves to be separated from gas mingled with steam has led to the invention of certain apparatus specially intended for cleaning-machines, which in a very high degree promote the formation of strata of the cleaning water, while at the same time the latter is forced to form effective water-strata for the condensation of the steam, and the reception of the water-covered dust particles. The coarser particles, on the other hand, are caught fairly easily by sprinkling water, or on passing the above-mentioned water-strata and surfaces.

We shall now describe some apparatus and machines for the cleaning of gas by the wet method, stating at the same time approximately the cleaning-power, the amount of water used, etc.

The *scrubber* usually consists of a lofty iron tower which is passed in counter-stream by the gas and the cleaning water. The latter is introduced from above, and is finely divided in various ways, by sprinkling or, still oftener, by the assistance of various kinds of scrubber

baffles, the object of which is to cut the water into thin strata of the greatest possible surface, and to diminish the rapidity of the fall of water. The hot gas is introduced from below, and forces its way up through the warm and finely divided cleaning water, a part of which is transformed into steam which is taken up and carried farther up to the colder zones, where it actively contributes in the usual way to the retention of the finer dust. The precipitation

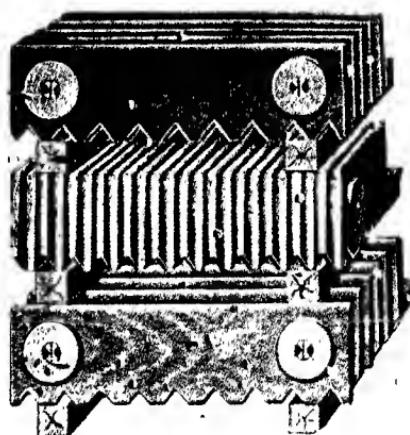


FIG. 6.

of the water-covered particles on the water-surfaces and baffle is facilitated by the many changes of direction following in close succession in the direction of the gas-stream. The baffles consist, as a rule, of wood laths of various shapes; iron plates are also sometimes used, such as, for example, that shown in fig. 5, as well as sieves and wire gauzes. Coke is less suitable as cleaning material in a scrubber for

blast-furnace gas, because the percentage of dust in the gas, before its arrival in the scrubber, is usually so high that the interstices between the lumps of coke soon get filled up. Fig. 4 shows a patented wooden baffle, the *Zschocke*. Older plants are often provided with several such scrubbers arranged after each other, which gradually reduce the dust percentage and the temperature. The great amount of space thus rendered necessary has had as a result that this construction is now less used, and constructions much narrower in form are employed instead, such as those shown in figs. 5 and 6. The first figure shows a scrubber with iron-plate baffles more than 85 feet high, intended to clean and cool 2,100,000 cubic feet blast-furnace gas per hour, with 2.5-3 grammes of dust per cubic metre of gas. The scrubber in fig. 6 really consists of three small scrubbers in series, built together, and provided with wood baffles. The gas is led from the blast-furnace by means of two pipes, 5 feet wide, which lead to the gas inlet of the dust-pocket. The apparatus, as a whole, is calculated to reduce the percentage of dust and the temperature of 1,100,000 cubic feet of gas per hour, from 4.8 grammes and  $46^{\circ}-200^{\circ}$  F. temperature to 1 gramme and  $105^{\circ}$  F. temperature respectively. The further preparation of the gas takes place by fans.

Amongst the newer kinds of so-called *cleaning-machines* may be mentioned those constructed by *Bian* and *Theisen*, and *fans with water-injection*.

The *Bian washer* is really intended for cleaning the whole amount of gas taken from the blast-furnace to such a percentage that the gas, without further cleaning, shall be fit to use for heating purposes. The cooling effect of the cleaner is also very good, as the gas on its exit usually proves to be cooled to a temperature only slightly exceeding that of the cleaning water supplied, which has probably contributed to the fact that the machine is usually known by the title of *Bian's cooler*.

The washer consists of an iron water-trough *M* (figs. 7 and 8), provided at the bottom with the pipes *F* for drawing off the mud, and at the sides with two bearings in which the shaft *W* is journalled. To the shaft

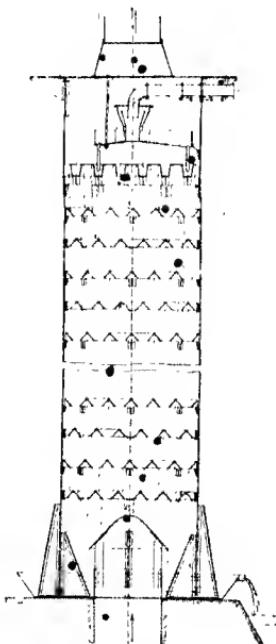


Fig. 5.

are secured discs **S**, which are provided with sector-shaped openings covered with wire gauze with about  $\frac{3}{8}$ -inch meshes. The water-trough is usually from 10-16 $\frac{1}{2}$  feet long and about 13 feet wide; the diameter

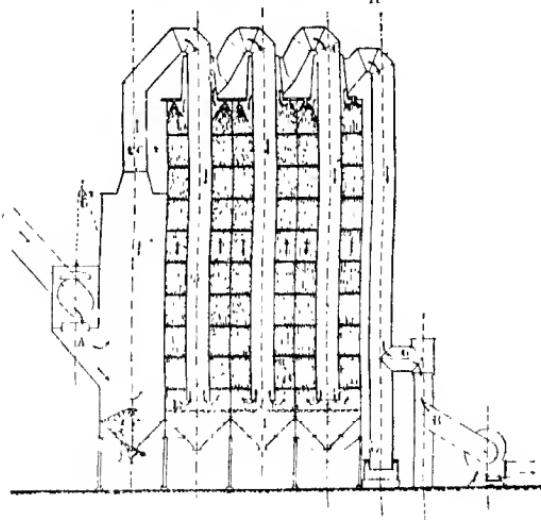
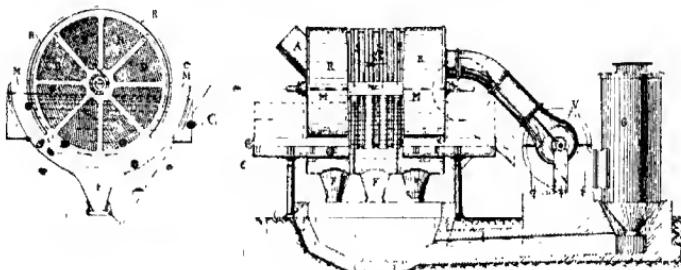


FIG. 6.

of the discs is 10 $\frac{1}{2}$  feet. The trough is kept filled almost to the brim with water, so that, during the rotation, new surfaces of the discs, which are sunk to almost one-half of their extent in the water, are kept covered with thin films of water. The discs **S** are surrounded



FIGS. 7 and 8.

by a rather narrow hood **R**, open at the bottom and provided with heads. The gas, which is taken from the blast-furnace at a temperature of 180°-390° F., is introduced at **A**, and passes through the upper part of the discs **S** in the direction of the arrow.

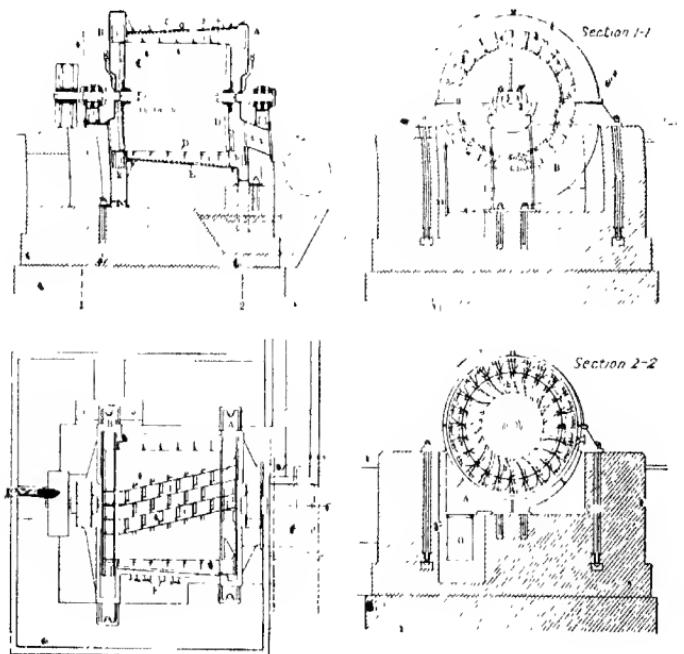
Following the gas from the inlet, the coarser dust is precipitated chiefly on the front discs, while the absorption of the finer particles takes place, with the assistance of the accompanying steam on its condensation, on the discs situated farther off. The enriching of the gas with steam out of the cleaning water takes place gradually, in accordance with the increase in the number of the discs passed by, until, at a certain disc, the gas is so far cooled that the formation of steam comes to an end; the thin films of water, which were formerly so effective for the precipitation of dust, no longer offer good condensation surfaces to the steam instead. The discs rotate at about 10 revolutions per minute, and, at certain intervals, are washed free from any deposits of dust by means of automatically acting flushing devices, in addition to which, the mud is now and then drawn off at the mud-pipes **F**. From the cleaner the gas is sucked into the fan **V**, where it is further cleaned by the injection of water.

The results obtained by this cleaner deal with dust percentages of about 0.5 gramme per cubic metre; the gas is cooled down almost to the temperature of the cleaning water, and in the process the cleaner is streamed through by the total amount of the gas, such as it leaves the blast-furnaces. A more effective purification for the purpose of being used as engine gas is afterwards carried out with a quantity of gas specially taken for the purpose, and with a dust percentage of 0.5 gramme. Amongst the other advantages of this washer may be reckoned the small consumption of power, amounting to about 10 H.P. for the rotation of the discs, and to 35 H.P. for driving the fan, as calculated for a blast-furnace of 100 tons smelting-capacity. In addition to this, there is the low water-consumption of 1 cubic foot per 1000 cubic feet of gas for the washer, and 0.5 cubic foot for the fan - these figures being for gas below 212° F.; while, on the other hand, the consumption, with gas-temperatures above 212° F., is stated to be about 2 cubic feet for the cleaner and 1 cubic foot for the fan.

*Theisen's rotary-washer* is shown in figs. 9 & 2, and consists of the suction-chamber **A** and the pressure-chamber **B**. The heads with the inlet and outlet for the gas are bolted fast to the conical hood of sheet-iron **C**, the inner surface of which is covered with the wire-gauze **E**. On brackets, cast in one piece with the heads, are two bearings in which rotates the shaft to which the drum **D** is secured. This is provided with vanes **H** and **K**, which, during the rotation, exercise a fan-like action on the gas, which, consequently, is sucked into the washer, in which it is cleaned, and from which it is afterwards discharged at a pressure of 2-4 inches of water. The long wings **I**, which are riveted obliquely on to the mantle of the drum itself, also force the gas into rotation in long, spiral-shaped paths, which considerably increases the cleaning power, as the gas is thereby retained longer in the washer. The cleaning water is led tangentially through the nozzles **F** into the cleaner, and runs out from the suction-chamber **A** through **G**.

The method of working of the machine is as follows: The gas is

introduced at **a** and is immediately caught by the vanes **b**, in which process the gas is first freed centrifugally from coarser dust, in order to be carried by the wings **i**, in counter-stream to the water, through the annular chamber between the drum and the hood. In this process the gas is pressed forward with a swirling movement, exercising a certain pressure against the water which is spread uniformly over the inner surface of the hood, which pressure, together with the difference in speed arising between the two media, produces frictional action



FIGS. 9-12.

between them which greatly promotes the precipitation of the dust. A great deal of the dust is at once flung out towards the hood, and is absorbed by the cleaning water; a part is caught by the water-spray in order to be afterward carried off in the same way, while, on the other hand—according to what the inventor says—the precipitation of the fine dust in this cleaner is chiefly to be ascribed to the condensatory action of the steam carried by the gas. This action is still further increased by the roughened washing surface caused by the above-mentioned wire-gauze.

Theisen proposed that the warm gas (the scrubber apparatus being omitted) should be led direct from the dry-cleaner into the cleaning-

machine, in whose interior part a lively development of steam would then take place. For the purpose of still further enriching the gas with steam, water can also be injected into the gas-piping by the aid of simple sprayers before the gas arrives at the cleaner. But, even if the cleaning power of the machine is thereby increased, we must not overlook the fact that, at such a high temperature as that at which the gas, under such conditions, enters the cleaner, the work of propulsion transferred to the gas by the machine, must be considerably greater than when the gas has previously been cooled in the gas-washer. This additional work should always be taken into consideration in calculating the working expenses, and this so much the more as the efficiency of the machine, in the respect mentioned, is doubtless considerably below that with which a well-constructed fan would carry out the same work.

The results with regard to cleaning capacity obtained with this washer are very good, however. By its use it is possible to reduce the percentage of dust from 3.1 grammes per cubic metre gas to 0.02-0.03 grammes, the consumption of water varying between 0.8 and 1.5 cubic feet per 1000 cubic feet of gas. The larger cleaners are driven by electro-motors, the smaller ones, on the other hand, by belting, at 300 to 450 revolutions per minute. These cleaners are made in sizes for 212,000 to 1,70,000 cubic feet of gas per hour. The power required may be calculated at 0.13 to 0.25 H.P. per 1000 cubic feet gas.

*Fans with water-injection* have come much into use during the last few years. In appearance they resemble the ordinary fans for the propulsion of air, although their details are more solidly made than they are in the latter kinds, in consequence of the more difficult conditions under which a fan of the former kind has to work. Thus, for example, the vanes and bearings of gas-fans are of more powerful construction than is the case with an ordinary fan. The cleaning with fans takes place by water being injected into the suction-pipe and spreading into the shape of a veil. Having thus been moistened, the particles of dust are afterwards thrown by centrifugal force out towards the circumference of the fan-case. From the bottom of the case the gas and mud are led off through a short rectangular outlet, which commonly opens into a large, high box, with an opening at the bottom, the interior of which is separated from the outer air by means of water, which reaches half way above the lower edge of the box (water seal). At its top, the box is provided with an outlet through which the cleaned gas is led off, while the mud sinks down through the box and runs off at the bottom.

In respect to the cleaning capacity a fan very naturally comes a long way after the Theisen cleaner, in which the gas and the cleaning water are compelled to act still more completely upon each other in counter-stream. With the fan, a reduction of the percentage of dust in the proportion of 10:1 is considered a good result with a percentage of dust of about 3 grammes per cubic metre; in some few

cases a cleaning of 12:1 seems to have been obtained. The consumption of water is here stated to have varied between 1.5 and 2 cubic feet water per 1000 cubic feet of gas for quantities of gas varying between 530,000 and 2,500,000 cubic feet per hour, and a corresponding amount of power of between 40 and 110 B.H.P. By letting the gas pass two fans placed tandem, both having water-injection, it has, however, been found possible to make the cleaning capacity 50:1 and even 200:1, with a power-consumption of 0.18, 0.28 H.P. per 1000 cubic feet of gas per hour. Two fans working together, with water-injection, therefore seem to be, as far as regards cleaning capacity and the necessary amount of power, comparable with a Theisen cleaner.

An attempt has also been made to lead the gas through three fans placed in series, of which the first two serve chiefly as cleaners; the third, on the other hand, separates the water from the gas. The high consumption of power and the complications which necessarily accompany this system should, it might be thought, have been a deterrent from making any attempt in this direction. For the drying of the gas there are, instead, cheap and easily handled apparatus to be had, which do the same service as a fan with its motor; and as regards the attendance of a cleaning plant with fans, this can be troublesome enough, even in the case of a cleaning apparatus on the two-fan system. The unavoidable variations in the amount of gas and in the temperature have, in a word, shown themselves to possess a disturbing influence on the co-operation between the fans, which often necessitates their being regulated by hand during the working.

When the gas has left the centrifugal cleaner last described, it ought to be purified to the prescribed proportion and well cooled, as the last phase of the gas-preparation. The *drying* involves nothing else but the removal of the water which has been carried along with the gas mechanically. For the purpose of drying the gas, *water-traps* and *filter apparatus* are employed. The former resemble the ordinary water-separators for steam, and the separation of the water from the gas takes place in the same way as in these, i.e. in accordance with the plan of separating the dust into the dust-pockets before mentioned.

As a rule, the drying with filters takes place after the gas has passed the water-separators, and then usually in high, cylindrical towers with several levels lying above each other, on which is spread the filter material, consisting usually of *wool-fibre* or *mineral-wool*. Saw-dust filters are also employed for the same purpose.

The good effect of a gas-holder of large volume, which is connected to the gas-piping between the drying apparatus and the gas-engine, on the composition of the gas, by diminishing the proportion of moisture, has, during the last few years, been more and more made use of, and this so much the more as the more perfect and easy drying in such a tank is usually accompanied by a decrease in the temperature of the gas. In addition to this, the arrangement also con-

tributes to producing uniformity amongst the more or less sudden variations in the composition and pressure of the gas.

The above description of the most usual apparatus and machines for the purification of gas, which are to be met with in a modern cleaning installation for blast-furnace gas, shows the direction which is nowadays taken in the erection of such an installation. Thus, in the typical cleaning apparatus for coke blast-furnace gas, the coarse dust is separated into *dust-pockets*, after which the preparation and cooling of the gas is carried out in *scrubbers* (or in *Burn* cleaners), and the final cleaning and drying in a *centrifugal cleaner* (Theisen cleaner, fans with water-injection), and *drying apparatus* (water-separators, filters, or gas-holder). A different method from this has been the carrying out of the final cleaning solely by the help of the Theisen apparatus or fans, as well as by the help of steam (Koerting).

In general, the power-consumption varies between 0.17 and 0.37 H.P. for the purification of 1000 cubic feet of gas, or, in other words, 1.7-4 per cent. of the power of the gas-engines are required to drive the cleaning machines, pumps, etc.<sup>1</sup>

The consumption of water has been found to vary between 3 and 8 cubic feet per 1000 cubic feet of gas.

The total working expenses for the purification of 10,000 cubic feet of blast-furnace gas, including interest and capital cost, seems, according to *Reinhardt*, to vary between 1d.-2d. (2-4 cents).

It seems as if there still remains very much to be investigated with respect to *the supply of gas for motor purposes* at blast-furnace works, and, even with the assistance of extensive material for observation, this question will scarcely be answered in a form so generally acceptable that sufficient information will be obtained to allow of its convenient employment in planning installations for the purpose mentioned. The loss at the mouth of the blast-furnace and, above all, the need of gas for the roasting-furnaces, hot blast-stoves, etc., depend on a number of uncertain factors, and vary greatly, even at one and the same blast furnace, according to the changes made in the charging and operation, etc. Only an exhaustive examination in each special case can spread light on the subject, but general examinations, however, will probably be none the less of great importance, and are calculated to direct attention to the possibilities, really existing, of an extensive and economical employment of this valuable by-product.

Highly illustrative in this connection are the results obtained by E. Hubendick's above-mentioned investigations at Swedish charcoal blast-furnaces, which may here be given briefly.

According to these we should be able to calculate, on an average, for every ton of pig-iron produced, of 5,160,000 B.T.U. disposable,

<sup>1</sup> If the gas-consumption is taken as being about 100 cubic feet per B.H.P. per hour.

which, transformed in gas-engines taking about 12,000 B.T.U. per B.H.P. per hour, will give

$$\frac{5,160,000}{24 \times 12,000} = 18 \text{ B.H.P.}$$

per ton pig-iron produced per 24 hours. The said surplus of heat, too, amounts to a little over 30 per cent. of the total heat-supply of the blast-furnace gas. At works with coke blast-furnaces, a surplus of 50 per cent. can often be reckoned on. Calculating 142,000 cubic feet gas per ton pig-iron, and with an effective heating value of 97 B.T.U. per cubic foot, we get for these latter furnaces :

$$\frac{0.50 \times 142,000 \times 97}{24 \times 12,000} = 24 \text{ B.H.P.}$$

per ton pig-iron, per 24 hours' production. That the surplus for engine-power is not as large at Swedish works as at other places depends in a great measure on the roasting of the ore which must necessarily be undertaken at Swedish works before charging, in which 20 per cent. of the gas is used.

#### (e) Coke-Oven Gas.

Coke-ovens give considerable amounts, not only of gas, but also of other by-products—tar, benzol, and ammonia. The employment in engines of the gas in question was at first attended with certain difficulties, but it is now coming more and more into use. The newer kinds of regenerative ovens give, on an average, 6000–10,000 cubic feet of gas per long ton of dry coal, according to the quality of the fuel. A fair idea of the properties of coke-oven gas may be gained from tests made at a coke-oven plant at Glassport, Pa., U.S.A.<sup>1</sup> The coal used had an average composition of 59.56 per cent. of fixed carbon, 34.6 per cent. of volatile hydrocarbons, and 5.84 per cent. of ash.

The composition of the gas varied within very wide limits during the coking process, and the gas consisted of

|                    | Per cent. by volume. |            |
|--------------------|----------------------|------------|
| Carbon dioxide     | CO <sub>2</sub>      | 4 – 2      |
| Carbon monoxide    | CO                   | 7 – 6      |
| Oxygen             | O                    | 0.3 – 0.3  |
| Heavy hydrocarbons |                      | 6 – 0.5    |
| Methane            | CH <sub>4</sub>      | 41 – 9     |
| Hydrogen           | H                    | 33 – 67    |
| Nitrogen           | N                    | 8.7 – 15.2 |

The figures in the first row give the composition after 1½ hour's coking, and those in the second row the composition at the end of the coking, after about 34 hours.

The effective heating value of the gas rose, during the first three hours, from 690 to 775 B.T.U. per cubic foot, but began then to fall off, and was at the end of the coking process as low as 340 B.T.U.

On account of these wide variations, it will, at least in most cases, be necessary to supply a gas-holder of sufficient size, so that the average gas drawn from it is fairly constant.

The total volume of gas generated per long ton of dry coal in this case was 10,390 cubic feet. If, however, we use the very conservative rating of 9000 cubic feet gas per long ton of coal, and a mean effective heating value of 600 B.T.U. per cubic foot, and if we further suppose 50 per cent. of the gas to be disposable for engine-power, and the gas-engine to require 12,000 B.T.U. per B.H.P. per hour, then there can be generated

$$\frac{0.50 \times 9000 \times 600}{21 \times 12,000} = 9.4 \text{ B.H.P.}$$

per long ton of coal coked, and per 24 hours.

The specific gravity of the gas, as compared with air, ranges from about 0.35 to 0.5. The small weight is explained by the relatively large proportion of hydrogen. The necessary volume of air theoretically requisite for combustion is about 4 to 5.6 cubic feet per cubic foot of gas.

## II. LIQUID FUELS.

### General Qualities.

The advantages of liquid fuel as compared with solid are, in many cases, numerous and important. For example, the ease with which it can be conveyed by means of pumps and pipes from one place to another, the possibility of storing it conveniently in tanks and cisterns, the comparatively large supply of heat per unit-volume of fuel, etc., contribute in many cases to its appearing to be a really ideal fuel. This holds good especially with regard to its employment for motor purposes. The fact that at first it was employed only for engines of small power, however, and amongst these, principally for the non-stationary, depended partly on the high heat-price of the fuel, and also on its great adaptability for the engines in question. It was not until the perfecting of oil-engines, and, above all, of the *Diesel motor*, that liquid fuel could come into question when greater power was demanded, as it then became possible to make use of cheap fuel-oils which, previously, could not be employed.

### The Physical and Chemical Qualities of Liquid Fuels as Characteristics of their Capability of being employed for Combustion Engines.

In judging of the suitability of a liquid fuel for these engines, the following qualities are of more or less importance, viz., (1) the effective

*heating value, (2) the volatility, (3) chemical composition, (4) specific gravity, (5) flashing-point, (6) viscosity.*<sup>1</sup>

All these characteristics, however, are not needed in order to discover in what degree a liquid fuel can be used for motor purposes, but it is usually the principle on which the engine works that determines to which of the qualities mentioned the greatest importance should be ascribed. Thus, for example, the knowledge of the specific gravity of one kind of petrol is sometimes enough to judge of its behaviour in automobile motors, while sometimes the chemical composition and viscosity are good guides, especially in the choice of cheap fuel for Diesel motors, for example. The most reliable method of judging whether a fuel can be used is, however, always its direct trial in working—the more so, because the consumption of fuel can be determined at the same time.

(1) The *effective heating value* per lb. of fuel increases, in general, with the proportion of hydrogen in the fuel. The distillates of crude mineral oil, such as Texas and Solar oil, kerosene (lamp-oil), petrol, etc., usually possess an effective heating value of about 18,000 B.T.U. per lb. The heating value for alcohol-fuels amounts, as a rule, to 10,000 B.T.U. per lb.

(2) *Volatility.*—At the beginning of this book we pointed out the necessity of the fuel being mixed, in an exceedingly finely divided state, with the combustion-air in the cylinder before ignition takes place. In the greater number of combustion engines using liquid fuel, we are in this respect dependent, in a very great measure, on the ease with which the fuel can be vaporised, as in that state the mixing with the air can be most securely carried out. Even if the process of finely dividing the fuel is preceded by a mechanical spraying by means of a pump or air-pressure, simultaneously with the injection into the cylinder against some glowing surface (hot-bulb), or into the greatly compressed hot combustion-air (Diesel motor), there is always a greater or a smaller part of the fuel vaporised before it is consumed.

The various fuel-oils present very great differences with regard to their volatility, according to their composition. Petrol, for example, becomes vaporised at the ordinary temperature of the air, and under atmospheric pressure becomes entirely so at 230° F., while American paraffin (lamp-oil, kerosene) requires a temperature of something more than 610° F. in order to boil. As every liquid fuel is a mixture of various hydrocarbons with varying boiling-points, the vaporisation of the fuel takes place gradually at increasing temperatures, until finally it becomes complete when the least volatile constituents have reached their boiling-temperature. Thus the kinds of petroleum

<sup>1</sup> *Viscosity* determines how many times a liquid is slower in its rate of flowing than water (Bigler's test). Viscosity changes very much with the temperature. Oils flow more easily, i.e. the viscosity is diminished, at high temperatures. Thus, for example, an oil at 32° F. may have a viscosity of 500, at 68° F. of 65, but at 100° F. only 15.

mentioned above give off 20 per cent. vapour at 300° F., 40 per cent. at 390° F., 70 per cent. at 480° F., and nearly 90 per cent. of the whole amount of vapour at 570° F. A number of heavier fuel-oils, on the other hand, require still higher temperatures for their complete vapourisation.

In many cases the mixture of fuel and air is prepared in a *carburetter* or heated *vaporiser*, in which process the air is sometimes previously warmed, which facilitates the mixture of the fuel-vapour with the air (the latter is saturated to a certain degree with vapour; cf. p. 71).

(3) *Chemical Composition*.—The combustible components of a liquid fuel consist chiefly of *carbon* and *hydrogen*, which, in the distillates of crude petroleum, amount respectively to 82-86 per cent. and 11-14 per cent.

The distillates of coal-tar (benzol, creosote, and anthracene oil, etc.) show on the contrary, about half as high a proportion of hydrogen, but a higher percentage of carbon, and so the composition as a rule contains about 90 per cent. carbon and 8 per cent. hydrogen.

The proportion of hydrogen in a fuel is often of great importance, as this proportion has shown itself to stand in connection, not only with the *inflammability* of the final mixture of the fuel and air, but also with the *capability of the fuel to give off gas on being heated*.

Very worthy of attention are *Ricppel's*<sup>1</sup> experiments concerning the capability of a number of liquid fuels to give off vapour and gas on being heated in closed vessels (calorimeter). The experiments were carried out chiefly with regard to the Diesel motor. All the twenty-six different kinds of fuel-oils which were examined were submitted to tests in such an engine, and very remarkable results were obtained. All the distillates of crude petroleum and lignite, rich in hydrogen, which were examined, showed themselves to be *employable*, while the distillates of coal-tar, benzol especially, proved to be more or less *difficult of combustion*, as the engine with these latter fuels worked with violent explosion shocks, and in a short time grew very dirty. An exception to this, however, was the oil called *liquid fuel*<sup>2</sup>—a distillate with a high proportion of hydrogen (a small proportion of benzol), obtained in Scotland by slow distillation at a low temperature from *cannel coal* or *Boghead slate*.

The laboratory experiments showed that the fuels rich in hydrogen (kerosene, Solar oil, Roumanian oil, paraffin oil, etc.) after having been to the greatest part vapourised in the calorimeter at a rising temperature, varying between 750° F. and 930° F., began to disintegrate into hydrogen, methane, and other gases. Benzol, on the other hand, did not show any signs of dissociation, although the pressure for this fuel was allowed to rise to as much as 100 atm. (1422 lbs. per square inch), corresponding to 690° F.

Whether a liquid fuel can be used in an ordinary Diesel motor or not

<sup>1</sup> *Z. Ver. deutsche Ing.*, 1907, Nos. 14-16.

<sup>2</sup> Not to be confused with a certain Texas oil of the same name.

is, therefore, considered by Rieppel to depend in an essential degree on the *gas-developing power* of the fuel. Thus, benzol showed itself to be *perfectly impossible* to use in the motor used for the experiments, although this fuel can be used with advantage in an ordinary automobile motor. According to what has been mentioned before, the benzol did not disintegrate in the calorimeter experiments; but, on the other hand, it can easily be vaporised in a carburetter and in the motor cylinder, in which latter it is afterwards ignited by means of an electric spark. The mixture of air and benzol vapour surrounding the spark is there exposed to an exceedingly high temperature, which brings about ignition, whereupon the heat extends to the rest of the mixture, which in its turn, begins to burn. In a Diesel motor, on the other hand, the fuel is brought to ignition by the temperature (about 930° F.), produced by the compression of the air, which renders impossible the formation of such high ignition-temperatures as in an explosion motor.

(1) The *specific gravity* of the liquid fuels diminishes, in general, in proportion as the percentage of hydrogen increases, and this, in accordance with what has been said above, influences the effective heating value of the fuel.

(5) The *flashing-point* determines that temperature at which a substance begins to give off ignitable vapour. Should the vapour of a fuel-oil be ignited at this temperature, it will burn at the surface without igniting the oil itself; it is not before the latter has been heated to the *burning-point* that the flame will be maintained by the oil.

Herem it is clear we must make a distinction between results obtained by heating in open and in closed vessels. The latter method, in which the dilution of the air and the cooling influences are excluded, is naturally the more correct one, and tests are mostly carried out in accordance with it in *Abel's* apparatus. All figures given below refer to tests in closed vessels.

(6) *Viscosity*.—In general, a liquid fuel, in order to be employable in a combustion engine, must not be too viscous, as, in that case, it would be difficult for it to flow through the piping and filters. It is also difficult then for the fuel-pump to measure off the small amount of oil necessary for every working-stroke. Two expedients are mostly used to escape from the inconveniences mentioned. The first one that presents itself is to *dilute* the thick-flowing oil with another one more thin-flowing. There is also the method of *warming* the oil—a method of procedure which has already proved itself to have good results, even at lower temperatures.

Some experiments have been made in this matter by the *A.-B. Diesels Motorer (The Diesel Motor Co.)*, Stockholm. Thus it was found that an addition of 5 per cent. kerosene (lamp-oil) made a certain Texas oil flow much more easily than the mixing the said fuel with 10 per cent. of Solar oil did.

In improving a thick-flowing oil by dilution with a thin-flowing one, we have, of course, besides paying regard to the economical

point of view, also to take into consideration the flashing-point of the mixture produced.

The above-mentioned experiments also showed that even a moderate warming of the oils ~~gas~~, in general, sufficient to make the fuels flow easily, without its being necessary to dilute them. The warming can be most suitably carried out by the help of the warm cooling water from the engine—a method of procedure which, in addition to being a very cheap one, also confers the advantage of limiting the highest temperature of the oil to that of the warm cooling water.

### Various Kinds of Liquid Fuel.

A huge number of liquid fuels of various origin, composition, and qualities have been examined, and have partly come into use for power purposes.

Amongst those most employed are the *distillates of crude petroleum*, as well as *alcohol* and *distillates of lignite*, while in England and Scotland *coal- and shale-oils* are used.

#### (a) Distillates of Crude Petroleum.

The chief places where crude petroleum is found at present are the oil-fields of *Baku* in *Russia*; those of *Pennsylvania*, *Ohio*, and *West Virginia*, in the *United States of America*; and of *Borneo* in the *East Indies*. It is found at many more places in *Europe*, too, among which, the oil-fields of *Galicia* and *Roumania* are those best known.

*Crude petroleum*, or *naphtha*, which, at most of the oil-fields, is usually got by boring, is a thick, greasy, and dirty liquid, with a penetrating odour. It consists of a mixture of liquid hydrocarbons of various character, which, on being heated, are vaporised at various temperatures. It thereby becomes possible, by means of *distilling* the crude petroleum, to obtain from them oils of various composition and qualities.

The distillates of crude petroleum can, with respect to their specific gravity and employment for motor purposes, be suitably divided into three groups, viz. *light oils*, *medium-heavy oils* or *camp-oils*, and *heavy oils*.

*Light Oils*.—Sp. gr. = 0.65-0.76. The *flashing-point* below 70° F.; the *boiling-temperature* under 300° F. First among these may be mentioned *petrol*.

*Petrol*<sup>1</sup> has a specific gravity ranging between 0.66 and 0.72, and the

<sup>1</sup> "Petrol" is often used as a summarising expression for various light oils. In the United States, especially, the following terms are used :

*Gasoline*.—Sp. gr. range between 0.660 and 0.670.

Boiling-point " " 158° " 176° F.

*Benzine*.—Sp. gr. " " 0.680 " 0.737.

Boiling-point " " 17° " 302° F.

Other authors give the sp. gr. of gasoline—0.636-0.657, and values differing still more will be found. (Cf., for example, Table I., page 5.) In the literature, "gasoline" is often used for oils which, according to the above, should really be termed "benzine."

boiling-point lies between 158° F. and 220° F. The effective heating value of petrol is usually stated as being about 18,360 B.T.U. per lb.; the lighter sorts show somewhat higher figures than the heavier ones. The composition is usually 14-16 per cent. hydrogen and 84-86 per cent. carbon. For its complete combustion, 1 lb. petrol requires, theoretically, about 185 cubic feet air (at 14.7 lbs. and 32° F.). In order to vapourise petrol of 32° F. initial temperature and at atmospheric pressure, there is required on an average 216 B.T.U. per lb. As the specific heat of the liquid petrol is about 0.5 B.T.U. per lb., 1 lb. of petrol at 62° F. will demand an amount of heat for its vaporisation amounting to  $216 \times 0.5 = (62 - 32) = 201$  B.T.U.

In general, the proportion of petrol which is obtained from American crude petroleum amounts to 10-20 per cent., and from Russian to 5 per cent.; Roumanian petroleum gives a somewhat larger percentage; Sumatra and Borneo oils are, on the other hand, worse. At present it is rather difficult to properly satisfy the colossal demand for petrol, and for that reason the oil refineries have lately been attempting to place the heavier petrol distillates on the market on a larger scale. Thus, for example, the German petrol factories have been pushing *Autonaphth*, *Motonaphth*, *Motorin*, *cloxin*, etc.

*Medium-heavy Oils*.—Sp. gr. 0.76-0.86. Flashing-point 70°-158° F.; boiling-point above 300° F.

Amongst the medium-heavy oils it is principally the *Russian* or *American paraffin* or *lamp-oil*—in the United States called *kerosene* or *high-test oil*—that is used. Viscosity low, 1.2-1.3 at 63° F., and thus the oil is very little thicker than water.

According to Professor Engler, there is obtained from the crude petroleum from Baku 32.51 per cent. lamp-oil, but considerably more, ~~up to~~ 75 per cent., from the Pennsylvanian. Thus the Russian crude petroleum gives, after the separation of the lamp-oil, an important remainder, “*Masut*,” which is principally used as raw material in the production of lubricants, and as fuel for ordinary fires. Russian paraffin has usually a specific gravity of 0.82-0.83; the American oil is lighter. Thus, for example, the specific gravity of *Standard oil* is given as 0.81 and of *Prime White* as 0.80.

The flashing-point is on an average 90° F. for Russian paraffin and 84° F. for Standard oil. Certain American lamp-oils of low specific gravity (below 0.80), which have been tried in combustion engines, show, however, a considerably lower flashing-point. The effective heating value for paraffin is usually about 19,000 B.T.U. per lb. The Russian paraffin is somewhat richer in carbon and thus poorer in heat than the American, which is richer in hydrogen. In the cylinder of an oil-engine, therefore, the former fuel stands a high compression better than the latter does. On the other hand, Russian paraffin needs, in general, greater heating than the American in order to be vapourised.

*Heavy Oils*.—Sp. gr. = 0.86-0.91. The flashing-point is usually 140° F.-270° F.

The employment of the heavy oils dates, in reality, from the first appearance of the Diesel motor.

*Solar oil* (which must not be confounded with the German distillates of lignite that go under the same name) is very light-flowing (viscosity 3.5 at 68° F.), and is in colour gold-brown to black-brown, and has usually a specific gravity of 0.86-0.89 and an effective heating value of 17,400-18,500 B.T.U. per lb. The flashing-point usually lies between 140°-270° F. (Abel's test).

*Texas oil* is more thick-flowing than Solar oil (viscosity varies very much, between 3-65 at 68° F.), and is also heavier than the latter. It is dark-brown or black in colour. The specific gravity often varies between 0.91 and 0.98, and the flashing-point of the oil lies between 130° and 270° F., while its effective heating value ranges between 18,000-18,900 B.T.U. per lb.

*Gelician oil* (Solar oil, etc.) usually has a specific gravity of 0.86-0.88, and an effective heating value of about 18,500 B.T.U. per lb.

A light-flowing distillate, "*Kraftogen*," which appeared in the market some years ago, has been examined at the Testing Department of the Stockholm Technical University. The specific gravity was determined at 0.877, the flashing-point and the burning-point at 163° F. and 300° F. respectively. The sample was free from water, and the effective heating value was 18,495 B.T.U. per lb.

*Borneo oils* have, at the same specific gravity, a lower viscosity than Texas oil. Thus, for example, a Borneo oil with a specific gravity of 0.949 had a viscosity of only 6.1. The specific gravity is usually about 0.95. On account of the great weight, the water and impurities are separated very slowly. The colour is a dark-brown or black. The effective heating value is lower than that of the Texas oil, being about 17,600 B.T.U. per lb. The flashing-point is generally rather high (for one sample 176° F.).

### (b) Alcohol.

Great efforts have been made, especially in Germany and France, to increase the production of alcohol for the benefit of the native industries and agriculture. It is mostly potatoes and grain that are employed as raw material.

The ordinary *methylated spirit* (or *denatured alcohol*) usually contains 90 volume-percentage of pure alcohol, and has a specific gravity of 0.834. The chemical composition in weight-percentage of such spirit is 43 per cent. carbon, 12 per cent. hydrogen, and 45 per cent. oxygen, and the effective heating value is about 10,300 B.T.U. per lb. 1 lb. of the fuel requires, theoretically, about 5.6 cubic feet air (at 14.7 lbs. and 32° F.) for its complete combustion. The spirit permits of the employment of high compression pressures (215 lbs. per square inch), whereby a very good thermal efficiency can be obtained. It has also the advantage that, in the case of the combustion being incomplete, it does not give rise to any unpleasant smell.

This latter advantage in regard to methylated spirits as compared with petrol, for example, has attracted much attention, especially as regards automobile motors, but in most cases the price has been a hindrance to the employment of the former fuel in preference to the latter. For this reason, especially in Germany, a mixture of alcohol and benzol has been used for automobile motors, hereby gaining a cheaper fuel, which also is more ignitable and possesses a greater heating value. As a rule, the most advantageous mixture employed is one of equal weights of spirits and benzol. When the mixture has the last-mentioned proportions, the effective heating value amounts to about 13,700 B.T.U. per lb., i.e. the heat contributed by the spirit amounts to little more than 37 per cent. of the total heating value! Another carburetting means for spirits is *Ergin*, which is produced by the distillation of coal-tar and lignite-tar.

#### (c) Distillates of Lignite.

From lignite-tar there have been obtained, especially in Germany, by means of distillation, oils which have been much used, for Diesel motors especially. The commonest are *paraffin* and *Solar* oils. The specific gravity amounts, in round numbers, to about 0.92 for the former, and 0.87 for the latter. The effective heating value is 17,500 and 18,000 B.T.U. per lb. respectively.

#### (d) Coal- and Shale-oils.

Amongst the number of oils in this category which are principally used in oil-engines, is the one produced in Scotland from shale—"Scottish shale-oil"—and benzol.

**Benzol.**—This fuel has, of late years, become a rival of petrol. Especially on the Continent it has sometimes been able to replace the dear petrol, with economical advantage, for use in automobile motors.

Benzol is got partly from coal-tar, from which, however, the percentage obtained is very small, and partly from coke-furnace gas, when about 6 lb. of raw benzol is obtained per ton of coal. The specific gravity of the fuel usually lies between 0.882 and 0.885, and the boiling-point of the greater number of its component parts is below 175° F. The fuel is completely vaporised at about 250° F. Its effective heating-value is about 17,100 B.T.U. per lb.

As benzol<sup>1</sup> is a distillate of coal, its carbon percentage is higher, but its percentage of hydrogen lower, than is the case with petrol. On account of benzol being comparatively poor in volatile hydrocarbons, the combustion-air is more difficult to enrich with this fuel than with petrol. (See p. 58.) Another inconvenience in respect to this fuel is that it solidifies when it reaches a temperature of 32° F.

<sup>1</sup> Chemically pure benzol is, in contrast to petrol, a fully definite chemical compound, with the formula  $C_6H_6$ .

Supported by the experience already gained in running automobile motors with benzol, this fuel seems, on the whole, to be preferable to alcohol, at least so long as the latter is not produced from cheaper raw material than it is at present.

*Swedish Shale-oil.* A light-flowing oil with high heating value has been produced from Swedish alum slate, and the *Diesel Motor Co.*, Stockholm, has tried this oil in one of its 10 B.H.P. engines.

The specific gravity of the fuel was 0.997, the flashing-point was 130° F., and it had an effective heating value of 17,187 B.T.U. per lb. Its composition was:

|          |       |           |
|----------|-------|-----------|
| Carbon   | 87.80 | per cent. |
| Hydrogen | 9.00  | "         |
| Sulphur  | 1.20  | "         |
| Ash      | 0.02  | "         |

The combustion was good, and the consumption of fuel low, being about 190 grammes per B.H.P. (metr.) per hour = 0.125 lb. per British B.H.P. per hour.

## CHAPTER III.

### PRODUCERS WITH ACCESSORIES: GENERAL PRINCIPLES OF DESIGN.

#### (a) The Producer.

THIS consists, in general, of the *base*, or *sole*, with grate, ash-pit, fire- and ash-pit doors, the *shaft* or *furnace*, which is lined with fire-bricks; and the *upper* part with the *charging apparatus*, the *fuel-container*, and the *vaporiser*.<sup>1</sup>

The *base* is generally constructed of cast-iron and, in the case of smaller producers, is often cast in one piece along with the *shaft-casing* (figs. 22 and 23).

The *ash-pit* is usually bounded at the bottom by a basin-shaped bottom cast in one piece with the base, and intended to receive the condensation-water which is separated from the mixture of air and steam, and often for the warm overflow water from the vaporiser (fig. 18). The water is kept constantly at the same level by the help of an overflow pipe and serves to quench glowing clinker and coal, which, especially during the removal of the clinker, very easily falls down from the grate. By this means the too early burning of the grate by means of radiant heat from beneath is prevented; the mixture of air and steam is not warmed unnecessarily, and thus further contributes to protect the grate and girders, at the same time that the formation of liquid clinker is thereby actively prevented.

The *fire-door* is, as a rule, omitted in the case of small producers, from which, in such a case, the clinker is removed through the opened *ash-pit* door. The upper edge of the frame of the door then lies at such a height above the grate that the latter, as well as the ash-pit, are easily accessible when it is wished to remove the clinker and ashes (figs. 22 and 23). The freedom from clinker in large producers is considerably facilitated by arranging cleaning-holes directly opposite to each other.

The *grate* is, in general, constructed as a horizontal grate with

<sup>1</sup> This is sometimes arranged in the immediate neighbourhood of the producer (tubular vaporiser).

$\frac{1}{2}$ -inch to  $\frac{3}{8}$ -inch air-spaces between the fire-bars, according to the size of the fuel. Small coal or dust-coal cannot be advantageously gasified on an ordinary horizontal grate, which in such a case should be constructed as a basket-shaped grate or step-grate.

The Grate-area can be made smaller for a producer than for a boiler, as in the former case the combustion need not be complete. The often small percentage of ash in the fuel employed for producers, together with the artificial draught with which they burn, contributes to make a further reduction in the size of the grate-area allowable. Further, it is plain that the determination of the grate-area necessary for a producer is not of the same importance for the economical utilisation of the fuel as is the case with the dimensions of the grate for a boiler. Thus the necessary quantities of air are measured out in the case of a suction-gas installation, almost independently of the size of the grate or the height of the charge, and mainly by the more or less powerful suction of the piston, according as the load increases or decreases. A small-sized grate, it is true, gives rise to greater resistance to the mixture of air and steam, and also causes it to stream with greater speed through the layers of coal lying nearest to the grate than is ordinarily the case, whereby the combustion zone and the reduction zone may very easily move upwards; these inconveniences, however will probably not make themselves observed until there is great deviation from the ordinary condition of things, if good fuel is used. For practical reasons, the grate-area should also be suited to the cross-sectional area of the shaft, which latter area is, in a certain degree, dependent on the fuel capacity of the producer.

The grate-area of a suction-gas producer may be chosen in agreement with the values given below:

Per square foot of grate-area per hour can be gasified 17-22 lbs. an hour, or 8-9 lbs. bituminous coal.

With the use of these figures, the weight of fuel to be gasified per hour will be calculated on the rated power of the engine (q.v. p. 27). The larger area needed with bituminous coal depends on the larger amount of ash in this case, and the formation of clinker, which becomes fused at high temperatures and renders impossible a proper maintenance of the fire-bed. In large producers especially the difficulties in stoking are much increased.

The combustion-air is introduced under the grate through a pipe leading into the ash-pit, which pipe sometimes in small producers, is either bent downwards or is cut off obliquely for the purpose of obtaining a more even distribution of the air; under larger grates, however, the air should be distributed either by means of several inlets, or by using special spray-pipes.

As we have already mentioned, the shaft-casing is sometimes cast in one piece with the base. As a rule, however, the casing is a separate piece screwed on to the base, which latter is then often provided with a broad flange going inwards, to which the casing and the girder-irons are secured. The flange also serves as a bed for the fire-brick lining of

the shaft. This consists of fireproof material, either in the form of radial bricks (for large shafts), or tongued and grooved interlocked segments (fig. 18). The brickwork is often not carried directly by the flange, but by an intermediate ring of fireproof cast-iron. The ring, which is exposed to great heat, should be made in parts, in order to be easily removable through the doors. Very often, too, it supports the conical part of the shaft (fig. 18), which forms the transition part between the grate and the furnace. In order to facilitate the repair of the producer body, the cone is usually built up as a separate part.

The *cross-sectional area* of the producer-shaft is often made larger than the grate-area, especially in large producers, in order that the shaft, for an assumed fuel-capacity, shall not be too high. When small anthracite (pearls) is gasified, the area should be somewhat enlarged, in order to avoid too great suction resistance. The fuel contained in the shaft holds, in accordance with what has been said previously, a supply of free and latent heat which is drawn on during the gasification of the fuel, and which is an active means of avoiding great variations in the composition of the gas at varying loads. In agreement herewith, producers for fuels *poorer in heat*, such as coke, lignite, peat, etc., are provided with larger shafts than corresponding producers for anthracite, wherein it is, of course, *the amount of heat given per volume-unit of the fuel* that determines the volume of the shaft.

For the same reason, large-sized fuel should be gasified in a larger shaft than small-sized fuel of similar composition, in addition to which, on determining the height of the shaft, it is necessary to take into consideration the *permissible charging-depth of the fuel*, which indicates to what height the fuel may be stored up in a producer-shaft without making the resistance, on the suction-in of the air, too great. The air, however, as well as unreduced carbon dioxide, often passes unhindered along through small fuel, which, in agreement with what has been said, presupposes a low charging-depth. On this account, a rather high fuel-column must be used, in spite of the resistance caused. The same holds good, too, of the fuels mentioned in the preceding pages, the physical qualities of which prevent the maintenance of an undisturbed gasification (cf. p. 10).

On the upper part of the shaft can also be noticed the gas-outlet, which, in order to prevent an uneven burning of the producer proper, is sometimes made as a separate part, consisting of an obliquely cut pipe of fireproof material (figs. 22 and 23).

As regards the *area of the gas-outlet*, the following figures may suit general conditions: Suppose 80 cubic feet gas at 32° F. to be generated per pound of anthracite (see p. 22), and the temperature of the escaping gas = 875° F. (see p. 16). The volume of the gas per pound of anthracite at 875° F. will then be 80  $\frac{875+459.4}{491.4} = 218$  cubic feet. Allowing a mean gas-velocity of 30 feet per second, the area of

the gas-outlet in square inches per pound of anthracite gasified per hour, will be

$$\frac{218 \times 144}{3600 \times 30} = 0.29 \text{ square inches per pound}$$

of anthracite gasified per hour.

In producers for bituminous fuel, the gas will leave the producer at a higher temperature, which should call for a larger area. This is, however, counteracted by the volume of gas generated per pound of coal being smaller.

Finally, the space between the casing and the lining of the shaft is filled with a heat-isolating substance, for example, *mineral wool* or *sand*.

The *charging apparatus* of a suction-gas producer usually consists of a *fuel-hopper*, provided with a fastening towards the interior of the producer (fig. 21), whereby the charging can take place during the operation without any great amount of air necessarily coming down into the producer-shaft and there mixing with the gas, which, in that case, could easily occasion dangerous, explosive combustions, in addition to impaired composition of the gas. The closing of the apparatus is most usually carried out by means of a *charging valve* and a *hopper cover*. The *valve disc* of the former is moved by the help of a lever provided with a counterweight, and the whole is in such a way balanced that, when fuel is being put into the hopper, the valve keeps closed by itself. When the hopper is filled with fuel up to the edge, the cover is put on, and the charge is then let down by moving the lever alternately up and down.

The charging valve is also made in the form of a *rotary valve* or a *gate valve* (fig. 19), etc.; the last-named, however, is only used with oil producers. In the case of the last-mentioned producers there is sometimes entirely omitted, amongst other things, the lower closing device (Koerting's producer, older type, figs. 22 and 23). In order, in such cases, to prevent the entrance of air into the producer during the process of charging, it is usual to make use of high fuel-hoppers, together with high fuel-containers. In spite of this, however, it has proved that, during the charging, the air manages to penetrate downwards to such an extent that it has acted injuriously on the quality of the gas. If, in addition, too long a delay in charging is made for one reason or another, the remaining low column of fuel offers only a slight resistance to the air which is forcing its way downwards, and this might, in a short time, give rise to explosive mixtures. These would then easily catch fire from the incandescent coal, and would burn explosively, with flames shooting out from the producer. On this account, the double fastening is preferable to the single one just named.

In order more easily to be able to free the generator-shaft from clinker which has burned fast to the walls, it should be possible for the hopper to be easily turned to the side, or to be turned upside

down (figs. 24 and 25); the poker can then be very easily put in through the large and convenient opening thus made accessible in the upper part, and the brickwork examined. This requirement is not, of course, necessary in the case of the fuel-hoppers, which are provided with slide valves.

The fuel which has been let down collects in the *fuel-container* before mentioned, in which it is partly both distilled and pre-heated (fig. 25). In order to increase the amount of heat obtained, the container is often prolonged downwards, and so is surrounded by the escaping hot gas (figs. 22 and 25). The lengthened part, which is a separate piece, thereby determines the charging-depth in the producer-shaft, and so alterations of the said part, on changing from one fuel to another, can easily be made. For example, by shortening the lower part of the container, anthracite producers can be altered to producers for coke, with the greater depth of charge and fuel-capacity necessary for that fuel. Producers with pan-vaporisers built into the upper parts are seldom provided with adjustable containers; the lower edge of the pan then usually determines the depth of the charge, and the fuel-container is then often arranged within the circular pan-vaporiser (fig. 18), or sometimes in an extra container arranged above the latter (fig. 19).

Finally, a high fuel-container contributes very effectively to diminishing the alterations in the composition of the gas, which accompany every charging (cf. p. 19).

#### (b) The Vaporiser.

As we have mentioned before, in the case of a suction-gas plant, the formation of steam takes place, as a rule, in vacuum, in a so-called vaporiser, which is heated by the warmth from the escaping gas. A distinction is made in respect to the placing of the apparatus between a vaporiser built in one piece with the producer (figs. 18 and 19) and an independent vaporiser (fig. 22).

Those belonging to the former class, which are used principally with smaller and medium-sized producers, are placed in the upper part of the producer, and consist, in general, of covered, ring-shaped cast-iron parts with concentrically raised bottoms, which latter measure contributes to the increase of the heating surface. This form of the apparatus has given rise to the name *pan-vaporiser*. By being placed in the upper part of the producer, the heating surface is exposed both to the warm gas that passes off and to the radiant heat beneath. The supply of water, regulated by means of a cock or a valve, runs down through a short feed-pipe provided with a collecting funnel to the vaporiser (fig. 18), in which the water is kept at a constant level by means of an overflow pipe. The lukewarm overflow water runs off visibly, so that the amount and temperature can easily be controlled. On the cover, which can easily be removed, we also notice the *air-intake* (figs. 19 and 20), and—usually exactly opposite to the former—

the *outlet for the mixture of air and steam*. The mixture is then led down to the ash-pit by means of an outer pipe (fig. 18).

The air which has been sucked in passes along close to the surface of the vaporiser-water of about 175° F., and thereby becomes heated. The ~~fixing~~ of the combustion-air with the steam takes place in this case by means of the evaporation of the water in the heated air, whose power of absorbing steam rapidly increases with the temperature. If it is pre-supposed that the air, during its passage through the apparatus, really *has time* to become saturated with steam to a degree corresponding to the temperature of the vaporiser-water, then the final proportion of steam for temperatures between 160° and 195° F. would vary between 0.275 and 1.42 lbs. steam per pound of air, corresponding to about 2 to 10 lbs. steam per pound of fuel; while, on the other hand, experience from economically working anthracite and coke-producers clearly shows a serviceable consumption of water in the vaporiser of only 0.3 to 0.7 lb. up to, exceptionally, 1 lb. The reason why it is considered inadvisable to increase the proportion of the mixture mentioned is explained farther on. With respect to the losses caused by cooling and the lowering of pressure in the piping, etc., it is clearly the *condition of the mixture below the grate* which alone determines the *real* amount of the steam introduced.

From what has been said, it follows that the production-capacity of the vaporiser depends, in a high degree, on the temperature of the heated water. Thus, an increase in temperature of only a few degrees brings about a noteworthy increase of the proportion borne by the steam to the air in the mixture of the two. This renders it possible to regulate the amount of steam in a simple manner, viz. merely by an alteration in the supply of water. *If, for example, it proves that the mixture-proportion, steam to air, ought to be increased, the supply of water is diminished; if, on the other hand, the supply of the latter is increased the proportion diminishes*, for the large amount of cold water, which, in the latter case, comes into the vaporiser, cools the water there until a temperature has been attained corresponding to the amount of steam needed, while the superfluous heat passes away with the overflow water.

If the supply of water is fixed, there are, however, presuppositions for the mixture-proportion which then arises, to remain pretty nearly unchanged, even when the load of the engine is altered; for if, for example, the load is increased, the development of gas will increase actively, the temperature of the gas will rise, and, with this, that of the vaporiser-water—*i.e., the greater amount of air sucked through is given the possibility of absorbing a corresponding amount of steam*. The accuracy with which this automatic regulation really takes place depends, too, on a number of incalculable factors, which have respect to the dimensions and shape of the apparatus, its position in the generator, the manner in which the load alters, the total volume of the other apparatus of the producer plant, etc. Thus, a heating surface of the form which is usually given to pan-vaporisers is not

very effective; and, as it is only incompletely passed over by the gas which has its outlet at the side, it is easy to perceive the difficulties attending such an apparatus with respect to its power of adaptability to varying loads.

Amongst the *advantages* of the pan-vaporiser may be mentioned finally, to begin with, a rather small size and a simple construction, which confer the advantage of great cheapness, accompanied by great

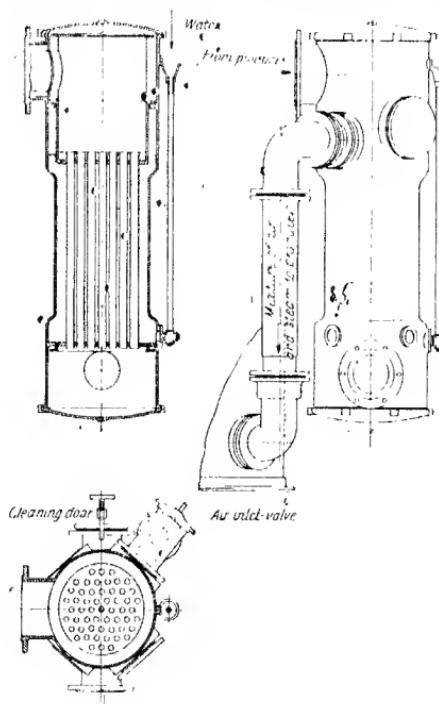
accessibility in the cleaning of the interior, and for inspection, and, finally, the simple care that is necessary. From the point of view of reliability in working, on the other hand, the criticism may be made, that a crack in the pan, arising through unequal expansion of the cast-iron caused by heating, may easily bring about a stoppage in the working, as this has really been occasioned by the cause mentioned.

The vaporisers belonging to the second class are usually constructed in the form of tubular vaporisers.

Figs. 13-15 illustrate such a vaporiser of Koerting's construction, and they show that the apparatus has a great resemblance

to an ordinary pre-heater. The nest of tubes, which can freely expand during the working, is thus passed through by the gas in the direction from above downwards, while the water circulates around the tubes in counter-stream.

The tubular vaporiser, with its very effective heating surface, makes it possible that the automatic regulation of the amount of vapour, after a rise or fall in the temperature of the gas, takes place more quickly than in the pan-vaporiser. But regulation by hand of the amount of vaporiser-water is required here too.



FIGS. 13-15.

Certain criticisms can be made respecting the tubular vaporisers. First, the cost of purchase and of upkeep, as well as the demand for space, are, of course, greater than in the case of pan-vaporisers. Then, too, the cleaning, including as it does the sweeping of the tubes and their being scraped free from incrustations, is somewhat troublesome on account of their inaccessibility, especially as regards the part of the work last mentioned. The leaking of the tubes, occurring every now and then, ought not to be any real hindrance to the future use of this apparatus, as such accidents are probably mostly derived from faults in the design or manufacture, and are also the result of carelessness (shortness of water, "going dry"). All these inconveniences appear, of course, to be greater in the case of smaller plants than of larger ones in which tubular vaporisers are very much used. The limit of the size of suction-gas plants which are furnished with pan-vaporisers seems, for the present, to be reached at about 100 H.P. per producer. The limits to the employment of the latter kind of vaporisers seem, in the first place, to have arisen in consequence of the difficulties which, when we take into account the small efficiency of pan-vaporisers, are a hindrance to the attainment of the highest possible heat-economy in the case of large plants. In a tubular vaporiser, on the other hand, there can be found place without any difficulty for a heating surface sufficiently large to easily satisfy the steam requirements of an economically operating producer.

The necessity of a more exact regulation of the supply of steam than the automatic regulation described above for the pan- and tubular vaporisers has, however, given rise to new methods in this branch.

Among these, practical employment has been found for the method of endeavouring to measure off exactly, by a mechanical method, the amount of water which is required for the occasion and, the next minute, to transform the same into vapour. Vaporisers of this kind are usually characterised by the employment of an automatic feed-water-regulator, which—under the influence of the increase of vacuum which periodically returns for every suction stroke of the engine—measures off certain amounts of water, which run down into a vaporiser without water-space, projecting deep down from the upper part of the producer, in which vaporiser the water is transformed into steam. The combustion-air, which is often pre-heated, streams through the apparatus and mixes with the steam, after which the greatly heated mixture of air and steam is led in the usual way under the grate. On p. 91 we find this method of regulation further described in connection with the *Nydpvist & Holm* producers.

The vacuum, which varies with the load, acts, in most instances, on a piston or diaphragm, which controls the regulation-valve for the water (fig. 26). The water is thus measured out in quantities approximately proportional to the vacuum mentioned, on which the amount of air sucked into the producer in the first place depends. It should therefore be possible to obtain a mixture of steam and air

of almost constant composition if the suction space of the apparatus is put in connection with some suitable part of the producer plant. The vaporiser, itself, or the air pre-heater, must naturally be considered as such a part in the first place, as it is the difference between the atmospheric pressure and the pressure prevailing in the said apparatus that chiefly determines the amount of air that enters the producer for the moment.

The said difference in pressure, and its periodical variations especially, are, however, all too small to permit of a good regulation by the help of the above-named apparatus. For that reason the regulator is usually put into connection with that part of the gas-piping which is nearest to the engine, where the suction influence of the latter can be felt with nearly unaltered strength. But, with such an arrangement, it is clear that the apparatus will regulate the amount of water rather in agreement with the load of the engine for the moment (suction action), than in accordance with the difference in pressure just mentioned, on the amount of which the quantity of air supplied chiefly depends, however.

The arrangements just mentioned will make the regulation dependent to a certain degree on the suction resistances in the plant, which can sometimes present fairly great fluctuations, especially in consequence of the formation of clinker in the producer and of deposits in the cleaning apparatus. It is evident that, under such circumstances, the engine exercises a comparatively more powerful suction, and that the supply of water may then become too large unless the lift of the valve is diminished by hand. In the case of an installation that is well cared for, however, these inconveniences need not at all occur. But the tendency to regulate too soon, however, will always remain as an inconvenience with this arrangement.

After the description and examination of the above-mentioned three commonest methods for mixing the combustion-air with steam, we may give a short account of the chief points of view that should determine the amount of the steam to be introduced. These are : *the economy of the gas plant, its reliability in operation and its care, and the reliability of the engine.*

The efficiency of a producer is, as we have seen by what has been said before (p. 12), increased by the addition of steam, and this showed itself to be especially the case when the greater part of the free heat of the gas produced was utilised for the production of steam. The limit of this utilisation—regard being paid exclusively to the gas plant—is, usually, the circumstance that the producer, in the event of its receiving an all-too plentiful supply of steam, can be so far cooled that the carbon dioxide passes off in great quantities un-reduced, and that a great part of the steam begins to leave the producer undecomposed. As far as these limits, the efficiency of the producer usually increases with the increasing amount of steam, although not at the same rate at the close as at the beginning of the addition of the steam.

The following experiments by Professor *Josse* with a 150-H.P. Deutz suction-gas plant may be here given as a good example of how the efficiency depends on the amount of steam.<sup>1</sup> Two comparative tests were made, viz. one with a scanty, and the other with a plentiful addition of steam. In the one case, the amount of steam came to about 0.18 lb. per lb. anthracite; in the other case, to about 0.72 lb. The change in the amount added was brought about in the ordinary way, already described (p. 71). In Table XI are given the heat-balances, together with the percentage composition of the gas on both occasions.

TABLE XI.

| Heat-balance of Producer.                              | Test with scanty addition of Steam. |             | Test with plentiful addition of Steam. |              |
|--|-------------------------------------|-------------|--|--------------|
|  | B.T.U.<br>per hour.                 | Per<br>cent | B.T.U.<br>per hour.                    | Per<br>cent. |
| <i>Amount of heat supplied per hour.</i>               |                                     |             |  |              |
| Weight of fuel $\times$ eff. heating value             | 2,095,100                           | 100         | 1,710,200                              | 100          |
| <i>Heat latent in the gas.</i>                         |                                     |             |  |              |
| Weight of gas $\times$ eff. heating value              | 1,730,000                           | 82.6        | 1,440,400                              | 86.2         |
| <i>Losses.</i>   |                                     |             |  |              |
| Free heat of the gas passing off (after vapouriser)    | 21,800                              | 1.0         | 29,000                                 | 1.1          |
| Heat carried away with waste water from the vapouriser | 94,800                              | 4.5         | 29,000                                 | 1.7          |
| Remainder (conduction, radiation, etc.)                | 248,400                             | 11.9        | 182,100                                | 11.0         |
| <i>Composition of the Gas.</i>                         |                                     |             |  |              |
|  | Volume, per cent.                   |             | Volume, per cent.                      |              |
| Carbon dioxide   | CO <sub>2</sub>                     | 1.5         | 4.7                                    |              |
| Carbon monoxide  | CO                                  | 31.0        | 27.4                                   |              |
| Oxygen   | O                                   | 0.6         | 0.4                                    |              |
| Hydrogen   | H                                   | 12.4        | 18.5                                   |              |
| Methane  | CH <sub>4</sub>                     | 0.5         | —                                      |              |
| Nitrogen   | N                                   | 54.5        | 49.0                                   |              |
| Estimated eff. heating value                           | 145.9                               |             | 147.2                                  |              |

<sup>1</sup> E. Josse, *Neuere Wärmeleistungsmaschinen*, 1905.

In the former case, the temperature of the vaporiser-water amounted on an average to  $180^{\circ}$  F.; in the latter case, by limiting the supply of water, the temperature was increased to  $200^{\circ}$  F., and so it follows, in accordance with what has been previously said (p. 71), that, with this higher temperature, there is also a greater enriching of the air with steam. The better utilisation of the free heat of the gas in the latter case is also clearly expressed in the difference between the amounts of heat carried off by the waste water, which amount to 4.5 and 1.7 per cent. respectively, of the whole amount of heat supplied. As is seen by the table, it was just the diminution in the above-mentioned losses which, almost entirely, brought about the increase of the efficiency from 82.6 to 86.2 per cent., proving the utility of utilising the free heat of the gas to a greater amount.

Attention has already been several times directed to the favourable effect that a rich addition of steam has on the reliability of working, and the care of a semi-water gas plant, especially in the case of clinkering coal.

If, on the other hand, respect be paid to the reliability of the engine—and especially when producer gas of varying composition is employed—then, of the combustible components of the gas, hydrogen is found to be the one which most easily produces irregular working, for the ignitability of the gas depends, in a very high degree, on the percentage of hydrogen, with which, other conditions being equal, it rapidly increases. As, in addition, the gas-engines of the present day, for economical purposes, work with very high compression, thereby intensely heating the charge, the necessity is seen of so far restricting the percentage of hydrogen in the gas that there will be no danger of the ignition-temperature being exceeded, *i.e.* that *pre-ignitions* can be avoided with certainty. For example, for the reason just given, the latter of the two tests just mentioned had to be carried out with a load of only 73 per cent. of the full power of the engine, as the gas, which contained as much as 18.5 per cent. of hydrogen, gave rise to pre-ignitions at heavier load on account of the higher temperatures produced inside the cylinder.

It is probably not possible to give, in general, the best proportion of hydrogen with respect to all three points of view simultaneously, as a number of conditions, especially as regards the cooling of the cylinder, the compression, etc., also influenced the determination.

For example, a number of engines work well with a hydrogen percentage of up to 20 per cent., while other engines show signs of irregular operation, even with such a low proportion of hydrogen as 10 per cent. In making such comparisons, respect should, however, be paid to the load for the moment.

#### (c) Cleaning and Drying Apparatus and Piping.

The real task of the cleaning apparatus of a suction-gas plant, for anthracite or coke, is to separate the particles of dust, soot, and ashes

accompanying the gas when it leaves the producer. On the other hand, the removal of tar is not aimed at in so great a degree by the cleaning (cf. p. 15). Thus the conditions are analogous to those prevailing at the cleaning of the blast-furnace gas.

Immediately after passing the vaporiser the gas is usually cleaned from coarser dust, and this cleaning either takes place in a special dust-collector, provided with a deflector which causes the gas to quickly alter its direction—in which process a part of the dust is flung out of the gas-stream; or some similar arrangement may be made in the vaporiser itself (fig. 19).

The real cleaning and cooling of the gas take place in the *scrubber*, similar to the cleaning of blast-furnace gas by the *wet* method (cf. p. 17). The apparatus consists chiefly of a steel-plate tower, the under part of which is often of cast-iron, this material offering a better resistance to the warm, corroding gases. The cleaning water is diffused in the upper part of the scrubber by means of sprayers or drip plates, and is divided and checked in its falling movement by a coke-filling resting on several grates of wood or iron. The gas is introduced at the bottom.

The dirty, stinking scrubber water collects at the foot, and from thence usually runs down into the *drain box*, which usually consists of a covered vessel into which the water prevents the outer air from entering ("water-seal") (fig. 24). In order to avoid the suction of the waste water into the scrubber, a difference of level amounting to at least 12 inches ought to be kept between the water-surfaces in the scrubber and in the drain box.

Sometimes the uncleared gas is led down into the scrubber water, and is thereby compelled to bubble through the same, in which process a part of the dust is separated from the gas, or the water, before it runs down into the drain box, passes the above-mentioned dust-collector, which is thereby continually washed clean. The last-mentioned devices, however, aim, in the first place, at bringing about a fully reliable shutting-off of the gas during the time when the plant is shut down, of which more will be said further on (p. 89).

The coke which is used ought to be hard and free from dust, and should be carefully washed clean. In order to avoid unnecessary suction resistance, the bits ought to measure at least 4 inches; and, in the lower layers especially, it is advisable, on account of the greater deposition of slime, to place there coarser coke, preferably between 6-8 inches in size. The putting in of the coke demands a certain amount of caution, and the throwing down of the coke, or the exposing it in any other way to be crushed, should be avoided as far as possible. A good way is to lower the coke in baskets, which are turned over by the assistance of a string fastened to the bottom. After the scrubber has in this manner been filled to a certain height, the filling is carefully washed clean, in which process the smaller bits of coke usually accompany the water down into the dust-collector and the drain box. Before the plant is taken into use it is, therefore, of importance to

remove these bits of coke, as otherwise, when the engine is at work, the waste-pipes may easily get choked up.

The amount of cleaning water which is used in the scrubber, under normal conditions, depends, just as in the preparation of blast-furnace gas to engine gas, not only on the cleaning capacity of the apparatus, but also on the cooling action to which the gas is exposed in the same. At all events, so much water at least should stream through the scrubber that the greater part of the steam present in the gas allows itself to be condensed, which, as a rule, is the case when the temperature in the apparatus is so far reduced that the gas-outlet of the apparatus feels cool to the touch. It not seldom happens, however, that the gas carries with it considerable quantities of cleaning water, which, however, can easily be separated, and is drawn off, either continually into another drain box out of the connecting pipe between the scrubber and the filter, or else periodically out of the gas-holder if there is no filter.

As regards the renewal of the scrubber coke, the lower third of the filling need not, as a rule, be renewed before 3-4 year's working, under the supposition, however, that cleaning water has been supplied in sufficient quantities.

After passing the scrubber, the gas has often to go through another cleaning process in the dry way, in a so-called *filter* or *dry scrubber*. In this the finest dust is caught, consisting of light ash, coal-dust, etc., which, in an ordinary scrubber, can be separated from the gas only with some difficulty.

The cleaning material consists nearly always of *coarse sawdust*, but sometimes, too, of *wood-fibre* or *fine-broken coke*.

When sawdust is employed, it is of great importance, in order to prevent the caking together of the mass in consequence of the moisture from the gas, that the latter be introduced into the cleaner in as dry a condition as possible. It is only exceptionally—viz. when the cost of a very thorough cooling and the accompanying drying of the gas is too high, and especially if the gas is not sufficiently free from tar—that finely crushed coke,  $\frac{1}{4}$  inch to  $\frac{3}{8}$  inch in size, is used as purifying material. The cleaning capability of such a purifier is, however, by no means equal to that of a sawdust one.

The *dry scrubbers* (*filters*) are, as a rule, round, and are provided with easily removable covers (fig. 24). The purifying material is spread on two to four wooden grates lying above each other and covered with shavings or coarse sacking. The gas enters from the bottom into the filter, and from there is led to the upper part by means of a wide pipe (fig. 24), in order to be cleaned afterwards in each of the layers on its way down.

The resistance to the gas in an ordinary sawdust scrubber is comparatively great (cf. p. 85), and increases, too, with time, in consequence of the accumulation of the dust, for which reason the filter must sometimes be cleaned and new sawdust put in. If the gas is free from tar, however, and is well cooled besides, a filter in

which coarse sawdust is employed can be used for at least six or eight weeks without any trouble from the resistance mentioned.

The utility of employing such filters is much debated. As a rule, no fine cleaning is used when perfectly good fuel can be obtained, such as, for example, English anthracite free from dust-coal. In such a case, rather than run the risk of increased cost of installation and upkeep, owners often undertake the more frequent cleaning of the engine which the simplification of its installation necessitates, unless they are prevented from doing this by working conditions, especially such as regard the time of working and reserves.

After the cleaning, the gas is usually conducted to a *gas-tank*, from which a suction-pipe leads to the engine. The placing of a larger volume of gas at the end of the piping prevents, in an essential degree, the arising of excessive variations in pressure which, unless checked, decrease the power of the engine and render its regulation more difficult.

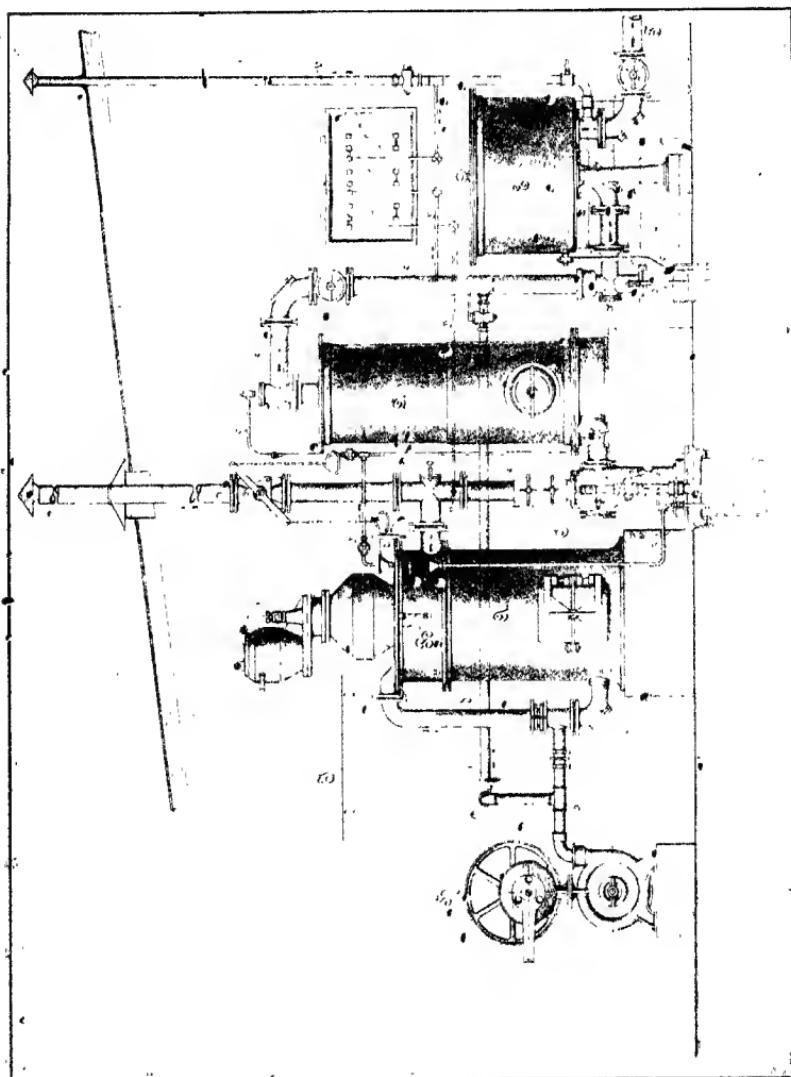
But such a tank, when it is large enough, can sometimes be of use for the production and preparation of the gas, too, as a longer time is given to the gasification in the generator to adjust itself to the new conditions, on account of the slower transmission of the suction action of the engine up to the generator, whereby the composition of the gas becomes more equal. In addition to this, the suction jerks in the generator are weakened, which contributes to the retention there of the smaller particles of soot, dust, and ashes. Finally, a part of the moisture of the gas is separated in the tank, where the speed of the gas is very slow.

The piping of a complete suction-gas plant embraces: (1) the main piping for the gas; (2) the vent-, blow-out-, and blast-piping; (3) piping for overflow and waste water; (4) piping for the water gas gas.

Even if experience shows that some of the piping mentioned in (2) and (4) can often be done without, without inconvenience, a description of a suction-gas plant with a complete set of piping should be of interest. As a good example, a suction-gas plant with pan-vaporiser and sawdust filter, by the firm of Pintsch in Berlin, has been chosen, and a view of it is given in fig. 16.

The *main piping* consists of wide cast-iron pipes provided with cleaning-holes at the bends, and made as straight as possible in order to facilitate the cleaning of the different parts of the piping. For the same reason the total length of the piping for the cleaned gas is kept as short as possible, by arranging the cleaning apparatus as close to the producer as possible.

Immediately outside the gas-outlet, the piping branches off upwards and downwards. During the working, the gas streams in the latter direction into the dust-collector **C** and the other cleaning apparatus, but during the starting and stoppages it moves in the opposite direction through the blow-off pipe, which is provided with a damper. When the filter **E** needs to be often looked to, it can be



entirely shut off from the rest of the apparatus by means of two valves.

The *Vent-piping* b (left) joins the discharge pipe from the hand-driven fan H to the main piping immediately in front of the filter. If the cover of the filter has to be taken off, the gas is first driven out from the same by the help of the fan, which fills the filter with pure air instead.

The *Blow-out piping* consists of the above-mentioned branch of the main piping together with a narrower pipe b (right) joining the gas-outlet of the filter with the open air. Through this latter pipe is blown out the remaining gas from the filter, on the ventilation of the same, and air, or gas mixed with air, out of the whole of the plant on starting again after a long stoppage, when the whole of the plant, before the resumption of work, is filled with fresh gas from the heated producer.

The *Blast-piping* a has its termination in the lower part of the steam- and air-pipe d.

The *Water-piping* has two branches, each provided with cocks, viz. the *feed pipe* f of the vaporiser, and the *inlet pipe for the scrubber water* g.

*Waste pipes* are arranged at the drain box for the condensed water from connecting pipes and filter.

The *Piping for the water gauges* p unite the main piping before and behind the scrubber and the blow-out piping of the whole plant, with three open water gauges.

During the operation, the reading on the last gauge will give the total of the losses of pressure in the producer, scrubber, and filter. The reduction of pressure in each apparatus consists, further, of the difference between the readings of the gauges after and before the apparatus in question. By every now and then making a note of these differences in pressure, a good idea is obtained of the state of the apparatus as regards cleanliness.

## CHAPTER IV

### GENERAL RULES FOR THE CARE OF SUCTION-GAS-PLANTS.

#### (a) Starting the Plant for the first time, or after it has been shut down for a long time.

BEFORE blowing up the fire in the generator the brickwork in the same, in order to avoid the formation of cracks, ought to be quite dry, the scrubber and the filter, in working order, and the vaporiser, the drain- and the seal-boxes filled with water. In addition to this, the producer is shut off from the rest of the apparatus by means of a water-seal (p. 89), or, where such a thing cannot be arranged, by the help of a change-valve (cock-valve) close to the gas-outlet of the producer (Chapter V.).

After this, the air inlet of the producer or the pipe for the steam-air mixture is closed, the damper in the blast-piping is opened, and, by means of the above-mentioned change-valve, the producer is put into connection with the blow-off pipe. The vent and the other blow-off piping and the gas-cock at the engine are, on the other hand, kept shut.<sup>1</sup> If the main piping is also provided with valves in front of and behind the filter, these are opened.

After having made sure that the effusing apparatus can easily be moved and is shut closely, the hopper is filled with fuel, and fire is made in the producer by the help of sticks, little bits of wood, shavings, etc., which are spread out on the grate, after which the fire is made livelier by blowing softly with the fan. Before doing this the fire- and ash-doors should be closed.

When the fire is burning strongly, we then proceed to fill the producer with fuel, during which operation the fan is kept incessantly in motion. At first only small amounts of coal are let down, after which the producer is charged in the ordinary way (p. 69) until it has been filled with fuel. When the blowing has continued from 15-30 minutes, according to the size of the plant and the skill of the man in charge, the gas formed is lit at the test cock close to the producer (the cock m, in fig. 16), and the gas is considered quite satisfactory if, while the fan is at work, the flame does not draw away from the mouth of the cock, but burn, steadily.

Then comes the filling of all the apparatus with gas. The fan is still kept going, and now, after the farther blow-out piping (behind the filter) has been opened, and the water-seal has been broken by drawing off the water, and after the blow-off pipe of the producer has been shut off, the gas is pressed in through the apparatus and out into the open air, in which process all the air is driven out of all the apparatus. Previous to this the scrubber water is let in.

In some plants the blow-off pipe from the producer, however, is only partially shut off while the filling takes place, as the blow-out piping behind the filter is very often not intended to carry off the whole of the gas which is developed in a warm producer. If, therefore, the producer is still to deliver good gas, a

<sup>1</sup> If the overflow pipe from the vaporiser opens into the ash-pit, the pipe should be closed before starting the engine, and opened immediately after starting.

larger outlet must be prepared for the gas, when is done in accordance with the above directions. As a rule, the gas is throttled in the blow-off pipe until the gauge behind the filter shows  $\frac{1}{2}$ -inch to  $\frac{3}{4}$ -inch pressure, water-column.

The filling of the gas plant must not stop before all the air and poor gas have been forced out, and until the gas which has been lit at the test cock at the engine burns steadily. While the trial is going on, the fan must incessantly be at work, as otherwise *an explosion inwards may take place*. In order to still further diminish the danger of explosion, both this test cock as well as that of the producer should be fitted with fine wire gauze.

If the whole of the plant is thus filled with good gas, the cock in the farther blow-out piping (eventually also the blow-off pipe of the producer) is closed, the fan is stopped, the cock in the pipe for the steam-air mixture (or the damper in the air-inlet of the producer) is opened, as well as the fire-door or the peep-hole in the same, after which the communication with the blow-off pipe of the producer is entirely shut off. Immediately after this the engine is started, after which the fire-door is again closed when the engine has made some revolutions.

It is of great importance that all handling of the apparatus, after the fan has stopped, should be done as quickly as possible, in order to prevent the cooling of the producer.

On opening the fire-door it is possible that a flame will rush out of the producer, which, however, will soon disappear after the engine has begun to run steadily. In the meantime, one should not place oneself in front of the door, or keep combustible objects there. If we neglect opening the door, *an explosion may easily take place in the ash-pit*, as the development of gas in the producer continues a while after the stopping of the fan. The gas at this moment endeavours to find a way down through the grate, and gradually forms an explosive mixture with the air in the ash-pit which ignites at the incandescent coal on the fire-bars. But as it is only small amounts of gas that can explode, and as, too, by means of the pipe for the steam-air mixture and the vaporiser, the ash-pit also stands in connection with the outer air, such an explosion is not very dangerous in its effects. But people who are standing close to the producer may be injured by the hot water thrown out from the vaporiser or, possibly, by the gas which streams out.

The formation of steam in the vaporiser ought to be hastened during the blowing, by admitting water in small quantities only (p. 71), until the water in the apparatus has become warm.

**(b) Re-starting the Plant after it has been shut down for a short time, such as Stopping for the Night, at Meal-times, etc.**

As the plant, after the stopping of the engine, is filled with good gas, and as all the apparatus behind the producer can be shut off from the latter by means of a water-seal or valves, these apparatus need not be filled anew, and so the whole preparation of the plant on such occasions is confined to blowing up the fire in the producer. This is undertaken in accordance with the regulations given in (a), with the exception of what has been stated concerning the lighting of the fuel, which is not necessary, as, during shorter stoppages, the coal is kept alight by means of the natural draught.

In addition to this, the time for starting the engine is determined exclusively by the appearance of the gas-flame at the producer. A gas-sample at the engine can, on the other hand, only allow one to draw conclusions as to the composition of the gas in the piping—in which, under ordinary conditions, good gas should always be found.

**(c) Working the Plant.**

After the engine has been started and the load put on, the water-supply to the vaporiser is adjusted, and the amount of water admitted to the scrubber is increased.

During the operation it is only necessary to inspect the producer at intervals of an hour or two, in order to supply fuel, or to rake out the ashes and clinker that may have formed. In order for the producer to give gas of even composition, the charging ought preferably to be done often; not later, at all events, than when the coal, which can be inspected through the peep-hole in the upper part of the producer, begins to turn red. The cover of the hopper, as well as other surfaces belonging to the charging apparatus which are exposed to wear, should be carefully cleaned from coal-dust, and the surfaces at which there must be no leakage, should be rubbed now and again with a mixture of equal parts of lubricating oil and lamp-oil.

A certain amount of caution should also be used with regard to any gas from previous fillings which may still remain in the hopper, and care should be taken never to touch both shut-off covers simultaneously, as an explosion may otherwise easily take place, in addition to the gas becoming deteriorated when air is sucked in from above. In order, too, to hinder as much as possible the air from forcing its way down into the producer when charging, the hopper should be filled to the brim.

The *freing from clinker* requires, on the other hand, greater practice and attention.

It is true that the producer permits the opening, without any danger, of the fire- and the ash-pit doors while the plant is being operated, for the purpose of breaking loose and removing the clinker; but, as every addition of air which has not passed the vaporiser reduces the heating value of the gas, the doors can, as a rule, be kept open only for a very short time. The raking out of the clinker and the ashes, therefore, ought to take place during stoppages (at lunch-time and in the evening) or with light load. The grate, on the other hand, ought to be cleaned every now and then, and the clinker broken loose from the lower part of the furnace, for which purpose the fire-door is often provided with a peep-hole and plug.

Clinker which has burnt fast to the walls, and which cannot be got at in that manner, is, on the contrary, removed from above by means of long pokers, which are either put down through the charging-openings in the upper part of the producer (*cf. p. 69*) or through a hole in the cover of the hopper. Such a cleaning can hardly be undertaken during the operation, but must usually be put off until the plant is shut down. If clinker is met with in large quantities, or in places difficult to get at, it will be necessary, too, to empty the producer entirely, in order to thoroughly clean the furnace.<sup>1</sup> As a rule, however, the cleaning can be undertaken without having to take out the coal or to put out the fire. In order to facilitate the work, the producer is usually charged more sparingly towards the close of the working-time, in order that the coal may not reach so far up in the shaft as during ordinary working.

Caution is advised when the shaft is being made available for cleaning from above. For if the coal remaining in the producer is kept incandescent by the help of the draught in the blow-off pipe (*cf. (d), below*), then, on opening, air in great quantities may be sucked down into the producer and be mixed with the gas, whereupon rapid combustions can occur, sometimes with flames shooting out of the producer. In order to prevent this sucking in of air, the firm Pintsch prescribes that the producer may only be cleaned while the blow-off pipe is kept closed, but still after the vacuum in the producer has been removed by the opening of the ash-pit door. Immediately after the furnace has been made accessible from above, the ash-pit door should, however, be closed again, as otherwise an upward current can arise. The different operations should, therefore, be undertaken in the following order:—

(1) *The ash-pit door is opened.* (2) *Communication with the blow-off pipe is shut off.* (3) *The furnace is made accessible for cleaning from above.* (4) *The*

<sup>1</sup> The deposition of clinker in the furnace is often *local*, the result of air-leaks existing there, round which the gas burns with great development of heat, and with the consequence that the clinker from the coal close by runs out and burns fast to the walls. Such a delicate and, at the same time, difficult place to get at in the furnace is, for example, the wall just above the fire-door which sometimes does not close quite tightly.

*ash-pit door is closed. (5) The poker is let down and the clinker is broken away from the walls of the shaft.*

In addition to this, after every removal of clinker, and every now and then during the working, the ashes and unburned coal which have fallen down through the fire-bars of the grate should be removed. The percentage of unburned coal in the ashes is often pretty considerable, especially when the producer is freed from clinker during the operation, and so the saving of such coal by means of sifting pays very well.

The suction resistance within each apparatus, as well as within the plant as a whole, can, at any time, be read off on the water-gauges, and it hereby becomes possible, especially as regards the scrubber and the filter, by means of a timely cleaning, to prevent the rise of an exaggeratedly great suction resistance, as the resistance within these apparatus slowly increases with time (cf. p. 81). In order to judge of the condition of a gas plant, the following table is given, made for a Pintsch's suction-gas plant with tubular vaporiser. According to this, such a plant can be considered to be in a good state, as regards the suction resistance, if the difference in pressure amounts to:—

|  |            |
|--|------------|
| For producer up to at most 1½ inches to 2 inches water-column. |            |
| „ vaporiser  | „ 1½ „ „ „ |
| „ scrubber   | „ 1½ „ „ „ |
| „ filter   | „ 3 „ „ „  |

which, together, give a vacuum of 6½ inches to 7½ inches water-column at the gas-cock of the engine. At starting, the pressures are usually somewhat higher than during the working.

#### (d) Stopping the Plant.

When the engine of a suction-gas plant has been stopped, the producer should at once be put into connection with the blow-off pipe, whereby, during the stoppage, a draught of sufficient strength is produced to keep up the fire in the producer. Before the engine has stopped, the peep-hole in the fire-door should be opened, however, or the door itself, in order thereby to prevent the gas forcing its way down into the ash-pit, where, according to what has been shown in (a), it might burn with great intensity.

After the scrubber water which is running off has formed a water-seal, the inlet piping for the cleaning water is shut off, and the water-supply to the vaporiser is so adjusted that the water in the same is replaced in the degree that it evaporates; a richer supply of water would only unnecessarily cool the vaporiser and render it more difficult to start again.

Before the removal of clinker, etc., is undertaken, the draught should be moderated by means of the ash-pit door, or the damper in the air-piping, until it is quite certain that the coal will continue to remain incandescent with the least possible supply of air. In any case, the plant must never be left before the above regulation has been carried out, if the best possible economy of fuel is to be obtained.

## CHAPTER V

### PRODUCER PLANTS BUILT FOR GAS-POWER PURPOSES.

With reference to what has already been said, we shall now describe some different producer plants, especially as regards their method of working and their construction.

#### I. PRODUCER PLANTS FOR FUELS POOR IN HYDROCARBONS, SUCH AS ANTHRACITE, COKE, Etc.

##### Dowson Gas Plant.

Fig. 17 shows a *Dowson gas plant* of older construction (cf. p. 18). The principal apparatus consists of the *producer A* and the *boiler B*, with the *steam superheater F*; further, the *water-seal box C*, the *scrubber D*, the *filter E*; and, finally, a *gas-holder*.

The boiler supplies superheated steam of about 60 lbs. pressure to the *injector G*, whereby the mixture of air and steam is continually blown into the ash-pit. The charging apparatus consists of *fuel-hopper* with *charging-bell*, and the fuel is put in, as a rule, every 15 or 30 minutes.

The way in which the production of gas in the producer is made to agree with the gas-requirements of the engine is worthy of attention. With the plant in question, the cock *I*, for admitting the steam to the injector, has been connected with the gas-holder in such a way that the supply of air mixed with steam is slowly reduced while the float is rising, in order finally to cease when the gas-holder has been filled. On the other hand, with increasing consumption of gas, when the bell sinks, the supply of gas is once more completed by opening the cock.

##### Suction-Gas Plant from Carl "Holmberg's Mek. Verkstads A.-B.

The construction of the plant is shown with all desirable clearness by the section in fig. 18.

The fuel-hopper has double shut-off arrangements, viz. a rotatable, tightly-sitting cover and a balanced charging-bell. The paths taken by the gas outside the producer are here determined by a three-way.

cock. Immediately above this, the vent-pipe from the self-sealing drain box issues into the blow-off pipe.

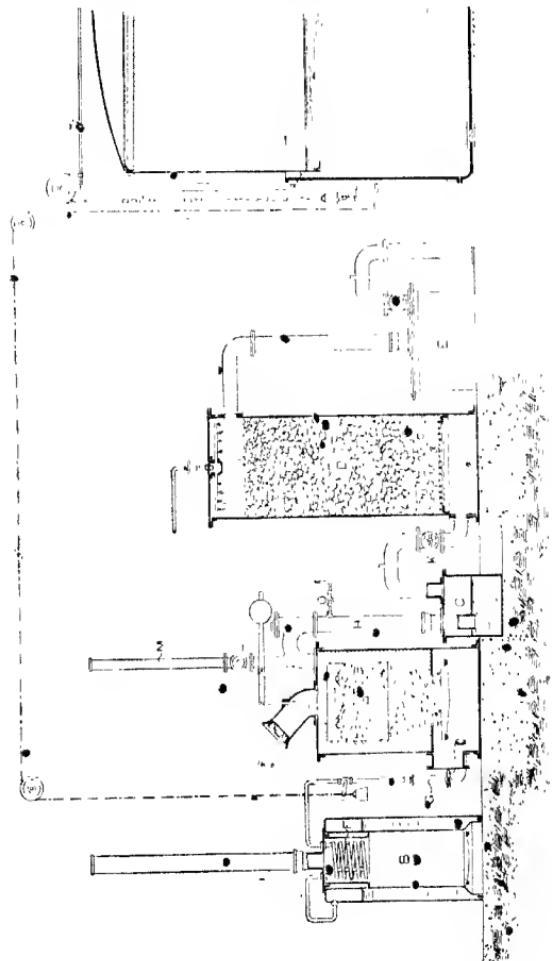


FIG. 17.

#### Tangye's Suction-Gas Plant.

Figs. 19 and 20 show a section and a side view of a Tangye's suction-gas plant of standard type.

The fuel-hopper is shut off by means of a cover and a slide valve, which latter contributes to make the furnace easily accessible for

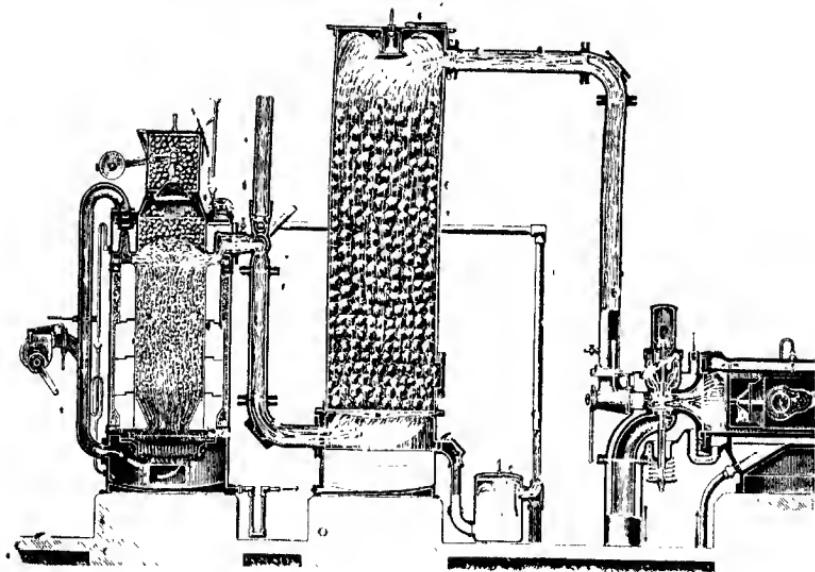
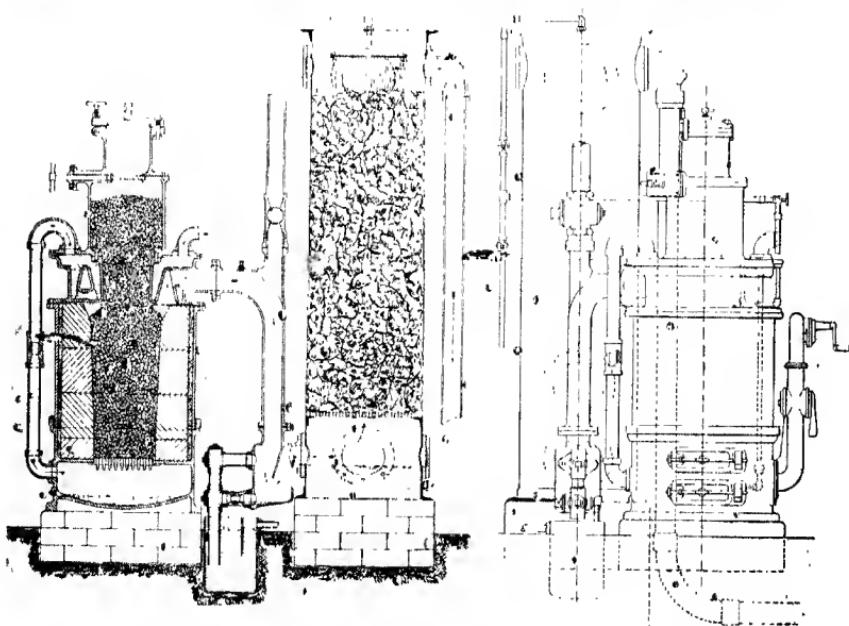


FIG. 18.



FIGS. 19-20.

cleaning purposes. In the dust-collector the scrubber water, after the engine has been stopped, forms a water-seal, the cock in the lower drain-pipe being then kept closed.

Suction-Gas Plant from the National Gas Engine Co., Ltd.

A section of such a plant is shown in fig. 21. The producer is provided with air pre-heater and vaporiser without water chamber. The water for the producer is pre-heated in the tube 15, which is washed.

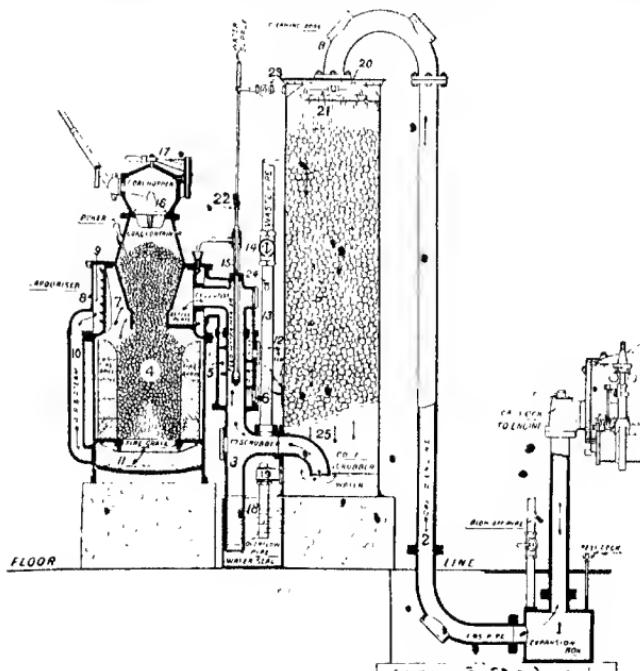


Fig. 31.

by the issuing hot gas, and then runs down along the upper part of the producer. Here it is transformed into steam on coming into contact with the outer surface of the shell 7, on which heat-intercepting ribs are cast. The vaporiser itself consists of the ring-shaped room between the outer shell 8 and the above-mentioned shell 7. Here the steam is taken up by the combustion-air, which is warmed in the air pre-heater 5 surrounding the gas-outlet pipe. As no water-space exists, the amount of steam developed is dependent, in a high degree, on the rate of water-feed. The water-supply can also be so adjusted that all the water is transformed into steam.

### Suction-Gas Plant from Gebrueder Koerting.

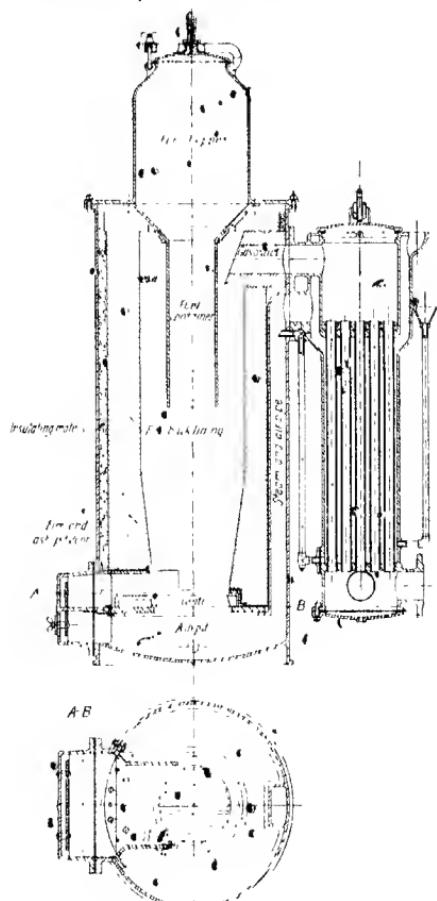
All the types of plants for anthracite and coke are provided with tubular vapourisers, and, as a rule, the cleaning of the gas is extended to the removal of the finest dust by means of filters. The producers are distinguished by the large fuel-containers, which are entirely surrounded by the gas (cf. p. 70).

A 40-B.H.P. plant is shown in figs. 22 and 23.

The charging apparatus which, in newer constructions, is supplied with double fastening, has already been described on p. 69. The producer casing is cast in one piece with the ash-pit walls, to which the canal for the steam and air leads down from the vapouriser, along the interior surface of the casing. The grate is made in one piece, and can be drawn out. It rests on a ring-shaped cast-iron plate supported by a flange on the casing.

Plants for greater power are made by the firm in accordance with fig. 24.

The producer casing consists, in this case, of a steel-plate cylinder, and to the charging apparatus belong an



Figs. 22-23.

oblique-lying hinged hopper and two shut-off discs, as usual. The pressure piping of the fan leads into the steam chamber of the vapouriser just above the water surface, and the overflow is carried down by means of the steam and air pipe. This arrangement of the

vaporiser between the fan and the producer makes it possible to blow up the fire with air mixed with steam—the consequence of which is that, when the engine is to be started, the producer, as well as the main piping all the way to the cleaning apparatus, stands filled with a gas richer in hydrogen than would be the case if the blowing were done with air only.

The path the gas takes beyond the vaporiser is determined, as usual, by the position of the change-valve. In addition to this, there is the usual drain box at the scrubber and two water-seal boxes, one on each side of the filter.

*Koerting's* producer for peat is described further on.

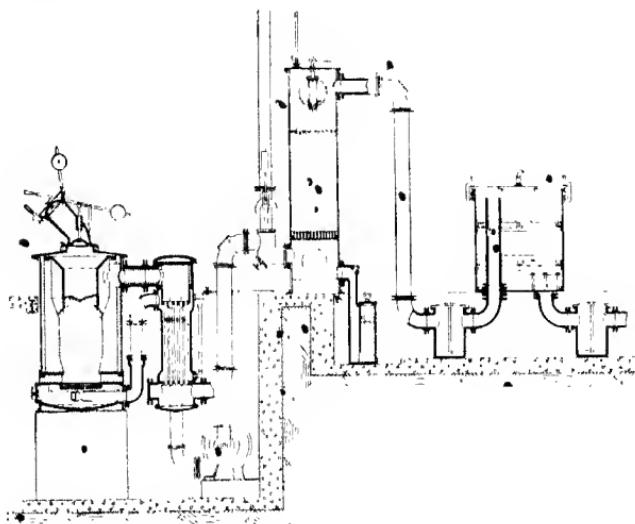


FIG. 24.

#### Suction-Gas Plant from Nydqvist & Holm.

Fig. 25 shows a 50-H.P. plant.

The producer, whose casing and bottom are of steel plate, is covered at the top by a cast upper part, in which is placed a ring-shaped pre-heater extending very low down. This latter, together with a cast-iron cylinder fastened to its under edge, forms the fuel-container.

Concentrically around these parts, and at some distance from them, is placed the ring-shaped, closed, cast-steel vaporiser. In this is vaporised the water injected into the pre-heated air, the amount of the water being determined by a feed-water regulator (fig. 26). The method of preparing the mixture of air and steam and the regulation

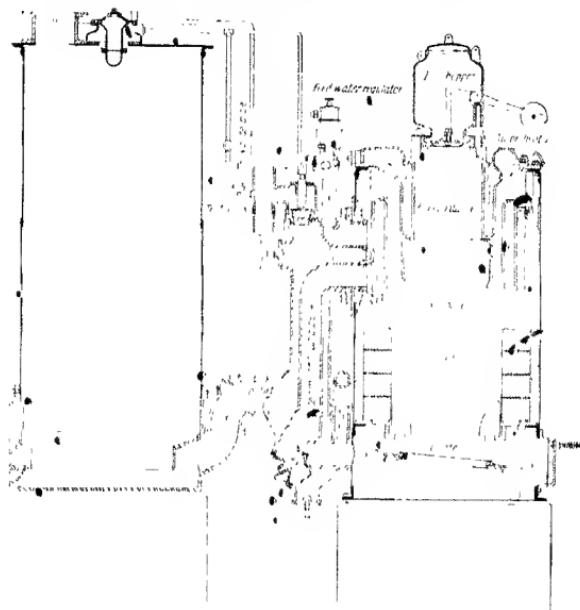


FIG. 25.

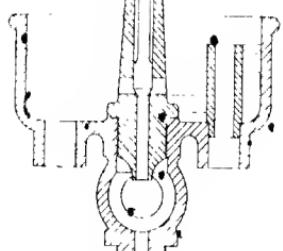
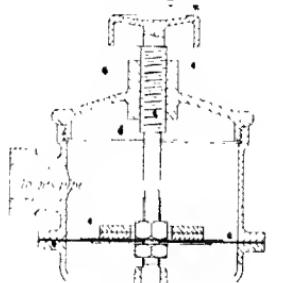


FIG. 26.

of the amount of steam in this producer have already been described in detail on p. 73. The feed apparatus is placed on top of the pipe for the pre-heated air. On the way to the ash-pit, the mixture is further heated by the escaping hot gas, which passes along the steam-air pipe. The valve arranged lowest down in this pipe is kept closed during the starting and during stoppages. Farthest down, the pipe is arranged as a dust-collector, and provided with a cleaning-door.

In the cast base of the scrubber the water forms a water-seal, which, during stoppages, shuts off the producer from the rest of the apparatus (cf. p. 77).

## II. PRODUCER PLANTS FOR BITUMINOUS FUELS, SUCH AS PEAT, LIGNITE, COAL, Etc.

### Koerting's Peat Producer.

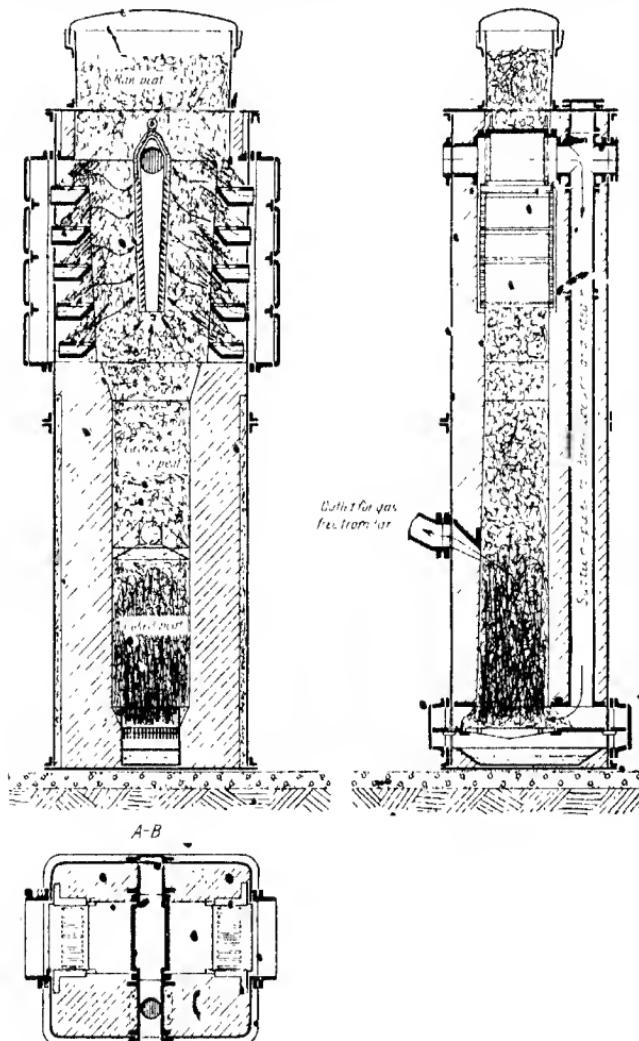
In figs. 27-29 a Koerting's suction-gas producer for peat is shown, in two vertical and one horizontal section.

The producer consists of a high, rectangular-shaped tower containing a firebrick lining, and is at the bottom closed by an ordinary grate. Above the shaft proper follows an enlarged part, the short sides of which are provided with a set of *grate boxes* placed loosely above each other, thus forming a step grate. In the frame for each opening there are arranged, for the purpose of attending to the grate, several doors provided with draught-regulating registers. Just between the openings of the grates there can also be seen a *grating outlet* provided with loose cast-iron laths, which outlet, by means of a *suction pipe*, stands in connection with the furnace right above the grate. The main gas-outlet, directed obliquely downwards, is arranged at about the middle of the shaft proper. The fuel is put in from above in a large hopper provided with a cover.

The generation of gas in this producer, which is intended for unscreened peat with up to 40 per cent. water, is carried out according to the method described in the first section of Chapter II., dealing with the generation of producer-gas from fuels rich in hydrocarbons.

When the producer is in operation, a part of the raw fuel which is sinking downward is retained on the projecting small grates, where it is completely consumed with a great development of heat. The column of fuel itself does not burn, however, but the hot products of combustion stream through it and thus *dry and distil* the peat (cf. p. 33). The tar vapours and steam driven off are sucked off through the grating outlet and are carried down through the suction-pipe into the combustion zone where, together with the combustion-air, they pass the incandescent strata of coal above the grate, being thus transformed into permanent gases (cf. p. 24). There is, of course, no direct loss of heat caused by the drying and the distillation. The lower part of the shaft receives the peat-coke remaining from the

raw peat and gasifies it, in which process producer-gas is formed by the action of a *primary current of air* (under the grate) in union with



FIGS. 27-29.

the steam from the products of distillation. There is thus no necessity for a vaporiser as long as fuel-peat with an ordinary percentage of moisture is employed.

In the upper part of the shaft, the coke forms a high protecting column which hinders a direct sucking-off of the products of distillation through the main gas-outlet. These gases, on the other hand, meeting with far less resistance on their way to the grating outlet, are sucked off through this latter and carried down to the grate. The regulation of the *partial suction action* of this producer has already been described on p. 26.

The advantages of this type of producer seem to lie in the effective drying and distillation of the raw peat by means of hot fuel gases, and that these latter penetrate the fuel in a horizontal direction and, thus under a resistance which is, it may be said, constant. Thanks to the good qualities of the peat-ash, the care of the many side grates is specially simple: the raking out of the ashes usually takes place once a day.

Gas analyses and tests of economy which have been carried out have been given on p. 26.

#### Pintsch's Coal Producer.

This firm, too, carries out the gasification in a number of its producers for bituminous fuels on the principle of the sucking away of the products of distillation, and their introduction into the zone of combustion. Fig. 30 shows such a producer and its vapouriser in section.

The charging takes place through the pipe **b**, from which the fuel glides down into the container **c**, in order there to be gradually distilled by the heat from the surrounding gas.

The gasification of the remaining coke then takes place in the furnace **d** below the container, in which process the air enters through the pipe **e**, in consequence of the suction action of the engine, and the gas passes off through the outlet **g**. The closed vapouriser supplies steam at 1.5 to 3 lbs. pressure, which is conducted to the injector **k**.

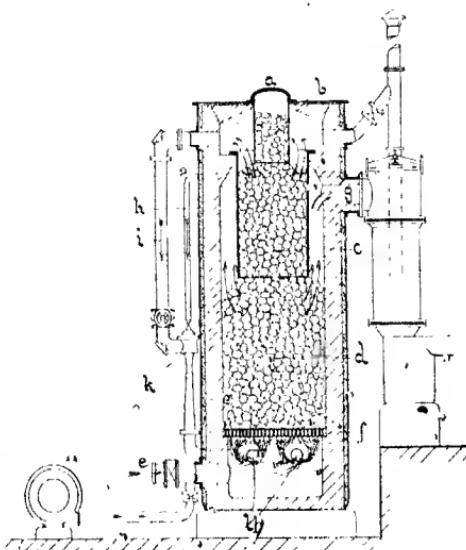


FIG. 30.

through the pipe **h**. This sucks the distilled gases out of the container **c**, through the pipe **i**, and presses them in under the grate **f**, above which they are consumed in an excess of air, in order afterwards to be reduced farther up into carbon monoxide and hydrogen. Through the outlet **g** the engine thus sucks out tar-free producer gas, which is afterwards cleaned and cooled in the ordinary way before being used.

The amount of the gases which are in this manner produced under the grate can be regulated either by a valve in the gas-piping above the injector or by varying the amount of steam. In the latter case the water-supply to the vaporiser is adjusted.

In newer designs the grate has been omitted as unnecessary, and is replaced by a ring-shaped *hearth*, greater in diameter than the shaft (fig. 31). The distilled fuel thus rests directly on the bottom of the hearth, and the combustion-air and the distilled gases are led in at

**o** and **p**. Pintsch's latest producers also show a water-sealed ash-pit, through which the ashes and clinker, especially from the middle part of the hearth, can conveniently be removed.

During the starting by means of the fan, no proper transformation of the distilled gases into permanent ones can, of course, take place, for which reason they

are simply blown upwards and are permitted to mix with the other gas. In some cases, trouble has been caused by the unpleasant smell of these gases, for which reason the blow-off pipe is nowadays provided with a burner, at which the gas burns continuously.

As regards the efficiency of the producer, the firm itself states that it amounts to about 70, 69, and 64 per cent. with full, three-quarter, and half load. The composition of the gas and the yield obtained with this producer are shown by the following results of tests with a 150-H.P. plant.

The combustible components of the gas consisted of 8.6 per cent. carbon dioxide, 18.3 per cent. carbon monoxide, 14.0 per cent. hydrogen, and 0.6 per cent. methane. The coal employed contained 76.74 per cent. carbon, and had an effective heating value of 13,050 B.T.U. per lb.; and it was shown that 1 lb. of coal gave 83 cubic feet gas with a calculated effective heating value of 110 B.T.U. per cubic foot (at 14.7 lbs. and 32° F.), so that the efficiency of the producer amounted to

$$\frac{83 \times 110}{13,050} = 70 \text{ per cent.}$$

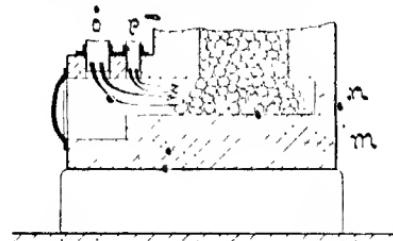


FIG. 31.

In the producer described above, a great number of different kinds of coal, as well as lignite briquettes, peat with low percentage of moisture, and raw, wet lignite, wood and moist peat, mixed with coal, anthracite, coke, etc., have been successfully gasified. The limits of size for coal are  $1\frac{1}{2}$  inches and 5 inches; the best size is  $1\frac{1}{2}$  inches to 3 inches. The amount of ash must not exceed 10 per cent. Caking coal ought either to be mixed with non-caking fuel, such as anthracite, coke, peat, lignite, etc., or else must be gasified in specially high furnaces in which the heating and distilling take place more slowly than in the standard producers.

#### •Deutz' Lignite Producer.

The method of operation of this producer is given on p. 28.

The gas plant (fig. 32) consists of the producer **A**, with its blow-off pipe, dust-collector **C**, the scrubber **D**, the piping with fan, change-valves, drain box, waste pipe **E**, and a water-separator **F**.

The producer is charged from above, through one or more openings in the head, which are closed by means of sand-sealed doors. Through the opening **B**, in the middle, secondary combustion air for the upper combustion zone is sucked in. The furnace is easily accessible for cleaning, both through the openings first mentioned as well as through some covered cleaning-holes situated above the gas-outlet. Between the gas-outlet and the dust-collector the main piping is partly lined with fireproof material. In the dust-collector the gas is freed from coarser particles of dust and ashes, which fall down into the water, here forming a water-seal for the producer. After the gas has passed the scrubber, its path, with ordinary operation, is first through the reversing cock and a U-shaped, upward-turned bend of the main piping, through a T-pipe united with the same, and finally through the water-separator.

After a stoppage, the development of gas is assisted, after the cocks have been reversed for blowing off, by means of sucking in air into the producer, by the help of the fan, which presses out the gas through the waste pipe **E**. During the stoppage itself, however, the combustion in the producer is kept up in the usual way by natural draught.

In starting up the plant from the cold, the following method is used.<sup>1</sup> On the grate there is spread a layer of wood and shavings, and, on top of that, coke  $1\frac{1}{2}$  inches in size, until the shaft, with the exception of about 16 inches, is filled by this fuel, on which again there is laid wood and shavings. Then the scrubber water is turned on, and the main change-valves reversed; the shavings both at the top and at the bottom of the shaft are lighted, and, finally, the fire is made to burn briskly by means of the fan, the ash-pit doors and the charging-covers, as well as the blow-off pipe of the producer, being kept open, but the fire-doors being, on the contrary, kept closed. When the coke at the

<sup>1</sup> A. Eckardt, *Die Gasmaschine, insbesondere die Viertakt-Gasmaschine*, etc., 1908, p. 61.

top is evenly incandescent, the charging with briquettes can begin, the above-mentioned doors being closed and the connection with the

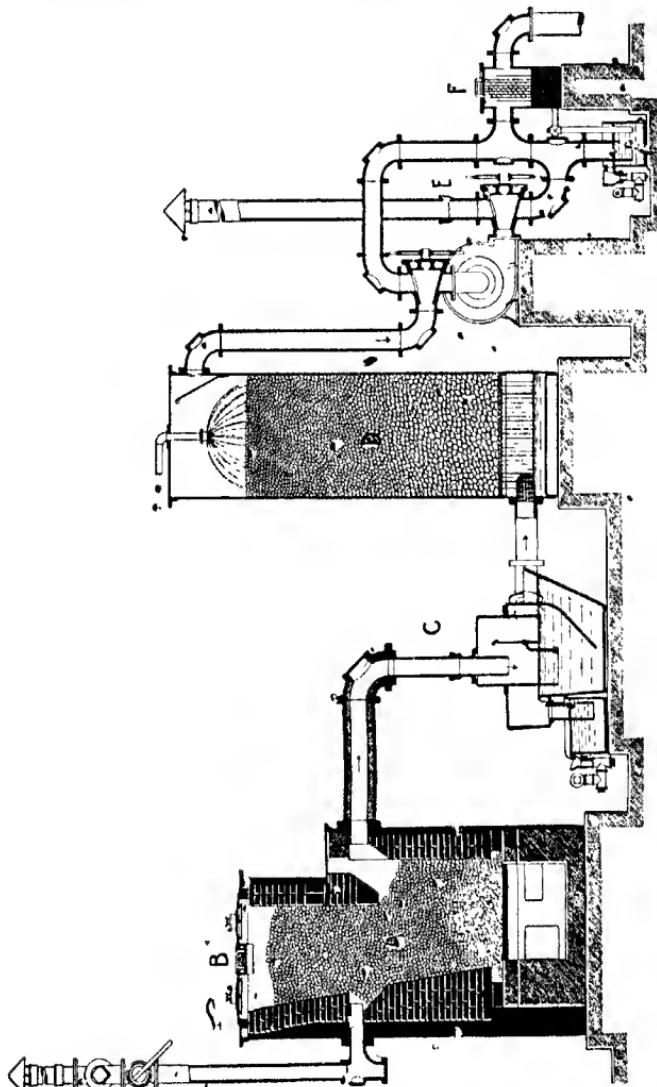


FIG. 32.

blow-off pipe shut off. While the fan is incessantly kept in motion, the gas is tested in the usual way, both immediately after passing the

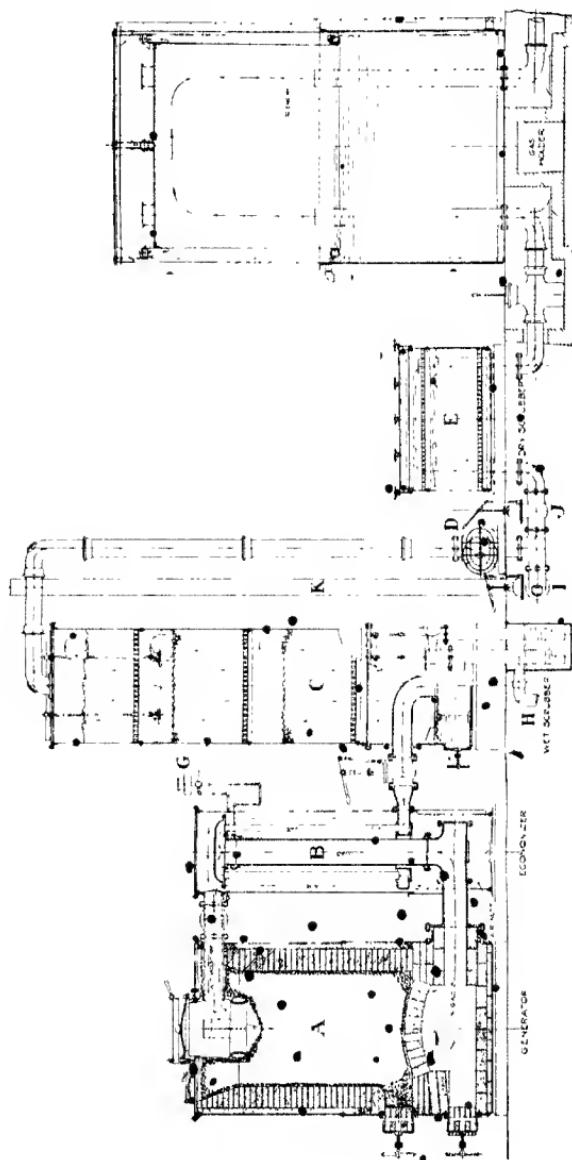


FIG. 33.

fan and on its coming to the engine. When the gas burns steadily at the last-named place, the fan is stopped, and the cocks are reversed for ordinary operation.

During the working there is usually a 2-inch to 4-inch vacuum in the producer, and a 5-inch to 10-inch vacuum at the engine. Plants of more than 500 H.P. usually require a strengthening of the suction caused by the engine, which is obtained by keeping the fan in motion during the working too.

In the producer now described it is said that peat with less than 20 per cent. of moisture can be gasified.

#### Loomis-Pettibone's Suction-Gas Plant.

The producer **A** (fig. 33) operates on the inverted combustion principle (cf. p. 27) and in accordance with the suction-gas system. Both the producer, the shell of which is of steel-plate, and the fire- and ash-pit doors are lined with extra fireproof brick. The grate, which is cupola-shaped, is also of brick.

The mixture of air and steam is conveyed to the top of the producer through a centrally-situated cylinder provided with a rotatable cover through which the fire can be inspected. The fuel is put in through several openings in the producer cover. **B** is a combined vapouriser and air pre-heater. The heated gas enters at the bottom and streams through a wide pipe on its way upwards, and through a large number of tubes on its way down to the gas-outlet of the apparatus. The supply of water is adjusted by means of the feed-water regulator **G**, automatically controlled by the vacuum variations in the inlet pipe for the mixture of air and steam (cf. p. 73). The water measured off is allowed to run down along the large gas-pipe from a groove arranged around the top of the same, in which process it is vapourised and then mixed with the air which is sucked in at the bottom, and heated by the tubes. In the upper part of the coke-scrubber **C**, the gas is dried in a layer of drying material (Excelsior) before it arrives at the filter **E**.

Producers according to this system gasify both anthracite and coke as well as bituminous fuels, such as coal, lignite, wood refuse, etc. According to the guarantees given by the firm, the efficiency reaches about 80 per cent., and there is obtained by the process a sufficiently tar-free and well-cleaned gas.

## PART II.

### CHAPTER I.

#### INTRODUCTION.

THE appearance in 1769 of Watt's steam-engine inaugurated a new epoch in the history of human invention. Generally speaking, it is to this ingenious invention that we have to ascribe the whole transformation of the economical life of the world that has since taken place.

During the time that has elapsed since the invention of the steam-engine, it has been more and more perfected; but, in spite of all improvements, it utilises, when at its best—which it seldom is,—only about 15 per cent.<sup>1</sup> of the available energy of the fuel. At the present moment it has to compete with a rival that utilises up to 36 per cent. of the energy supplied. The competition commenced with the introduction of combustion engines taking for their share the small units of power—the power needed for small industries. Then came the turn of the larger units. Still, the gas-engine kept itself within the limits of a few hundreds of horse-power. Then, during the course of a few years, it found its way into iron- and steel-works, where it made use of the gases which, hitherto, had been utilised only on a small scale, or with poor effect. But here greater power was demanded. Under unheard-of difficulties, technical skill succeeded in producing the necessary engines; solved, at least, the most prominent difficulties; but, in doing so, it had to revert in many respects to the principles of design that had been adopted for the modern coal-saving and reliable steam-engines.

After having been applied to stationary engines, it had to be applied to the most important of all—the locomotive engine. Here, too, small amounts of power were at first all that were needed. The sport and pleasure industries united, and small petrol motors were mounted in boats and carriages. These were merely interesting experiments, however, but the work of remedying shortcomings went rapidly forward. At the present day the motor-car and the motor-

<sup>1</sup> Tests with steam-locomotives have given as much as 23 per cent.

boat are already widely employed as means of communication, and internal combustion engines have already improved so greatly that they are making their way into every navy. As yet, it is only the submarines that they have conquered, but they are well on the way to take over all swift-going vessels of smaller size, torpedo-boats to begin with. And after having been adapted to the needs of the fishing industry, the internal combustion engine is now being adapted to the needs of other vessels of smaller and medium dimensions.

From this short review we find that combustion engines have not only opened new fields of operation, but are now also pushing their way into places where formerly the steam-engine was supreme. One might be inclined to find the chief reason of this rapid success in the fact that combustion engines utilise their fuel so much better. But, whatever the importance for the success of a machine-type fuel-economics may be, there are other points of view which are as weighty, or even of more importance. It not seldom happens that the higher or lower price of the fuel used, or some percentage better utilisation of the fuel in the one machine or the other, is of less importance in comparison with such points of view as the cost price of the engine, the amount of attention required, the demands of space, and, in certain cases, weight, and—first and foremost—reliability and ease in regulation. It is not any one of these points of view but all of them together which, in each special case, decide which kind of engine should be thought of. It must be said in favour of the steam-engine that it is not so very long ago that, in very many respects, it was unequalled, especially with regard to reliability, ease in regulation, and the possibility it allowed of overloading. During the last few years a great and gratifying change for the better has taken place in this respect as regards combustion engines. Nowadays, the gas-engine, as long as it is supplied with suitable fuel—which, we are sorry to say, is not always the cheapest—and if it is properly attended to, gives fully satisfactory results. Still, it often demands that the load shall not vary too much. As far as regards small oil-engines, at present they suffer very generally from certain inconveniences; but it is to be expected that these engines, too, will very shortly attain to a higher grade of perfection.

In what has just been said, the steam-engine has been taken as the standard of comparison, and in the following pages we shall find how the advantages and the disadvantages of internal combustion engines are, in the most intimate way, bound up with the difference in the working of these two kinds of engines. As a matter of fact, the principal difference is that, in the case of the steam-engine, the heat-energy of the fuel is liberated, and transferred to the working medium (steam) outside the engine itself; while, on the other hand, in the case of the combustion engine, the heat-energy of the fuel is liberated within the cylinder of the engine. In this fact lies the fundamental cause of the triumphal progress of the combustion engine; but herein, too, lies the secret which still hinders its further development.

## PRINCIPAL POWER-CYCLES OF INTERNAL COMBUSTION ENGINES.

### I. EXPLOSION ENGINES.

The real history of internal combustion engines begins with the year 1860, when a Frenchman, *Lenoir*, came forward with a gas-engine, 3-inch diameter cylinder and 5-inch stroke, which, in a higher degree than before, attracted attention to this kind of engine. It worked without cooling jacket, was double-acting, and provided with electric ignition. As, however, the engine worked without compression of the charge, and as it was imperfect in other respects, it was very uneconomical in its working. An improvement was made in 1877, when *Otto's* four-stroke gas-engine made its appearance, with compression of the charge before this latter was ignited close to the dead centre.

The principle on which this engine worked, and which, even to-day, is the one most employed, is called the *four-stroke cycle*, or *four-cycle*. Sometimes it is also called the *Otto cycle*, or the *Beau de Rochas cycle*. The latter name comes from the fact that a French engineer, *Alphonse Beau de Rochas*, in a little pamphlet published in 1862, laid down the theoretical fundamental principles for a gas-engine which should, in thermal respects, give economical results.

#### The Four-Stroke Cycle.

Distinctive of this principle is the double employment of the piston, viz. both as pump- and as working-piston.

Let, in the indicator card (fig. 34), the volume of the gas present in the cylinder at different parts of the stroke be measured along **MP** beginning from **M**, and the pressure of the gas along **MN**, also reckoned from **M**. Let **AB** be the atmospheric line. The distance between **AB** and **MP**, = **AK**, is then 1 atm. **MK** is a measure of the compression-space of the engine, and **AB** a measure of the piston displacement.<sup>1</sup> The working of the engine is then as follows:

*1st stroke = the suction stroke.*—The piston, at the beginning of the stroke, is at **A**, and the inlet-valve is opened simultaneously or a little before. When the piston moves outwards towards **B**, the charge<sup>2</sup> is drawn into the cylinder. But, as this suction is attended with resistance in the pipes and valves, the pressure in the cylinder sinks somewhat below atmospheric pressure, and is represented by the line **AHL**. When the piston has come to the end of its stroke at **B**, the inlet valve is closed, the piston returns, and

<sup>1</sup> By the *piston displacement* is meant the volume moved through by the piston during its stroke; i.e. the effective piston-area (piston-rod area deducted)  $\times$  length of stroke.

<sup>2</sup> The mixture of gases and air that is, or has been, drawn into the cylinder, and which has not yet been brought to combustion, is frequently termed in the following pages, *the charge* or *the explosive charge*.

The 2nd stroke, = *the compression stroke*, begins. The piston moves in the direction from **B** to **A**, and in doing so compresses the charge within. The pressure rises along the curve **LC**. When the piston has ended its stroke again, the compression-pressure is represented by **AC**. Its amount is determined chiefly by the volume of the compression-space, **MK**, which, in every case, must be kept so large that the final compression-pressure, **AC**, does not reach that height at which self-ignition of the gas takes place. Just before the piston has reached its end position **A**, the gas is ignited by an electric spark, let us say. The charge now burns hastily—"explodes,"—whereby the pressure more or less suddenly rises to **D**. The piston turns, and

*The 3rd stroke = the expansion stroke, begins.* During this stroke

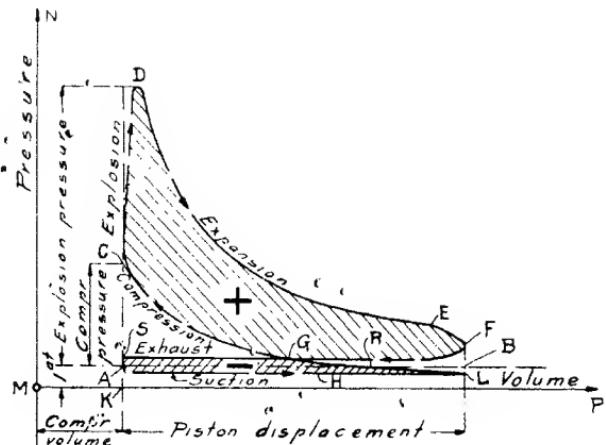


FIG. 34.

the gas drives the piston outwards, during which process the pressure sinks along the curve **DE**. About  $30^{\circ}$ - $60^{\circ}$  before the crank has reached the outer dead centre, there is opened at **E** an exhaust-valve, whence the burned gases quickly stream out, bringing about a lowering of the pressure to **F**.

*4th stroke = the exhaust stroke.*—The piston moves inwards again, driving the burned gases before it out into the open air, through some silencer or similar contrivance. This removal of the waste gases from the cylinder is called *scavenging*. The pressure is represented by the curve **FGS**. In the neighbourhood of **A** the exhaust-valve is closed and the inlet-valve is opened, after which the *power-cycle* or *working-cycle* or *cycle*, as it is variously called, begins once more.

It is seen from what has been said above that, out of the four strokes of the piston, there is only one—the third—that is a working-

stroke. During both the first and second, as well as the fourth, strokes, the piston must be driven along by that energy which has been stored up in the fly-wheel during the third stroke. Partly on this account, and partly also because the explosion-pressure employed is considerably higher than the steam-pressure in the case of steam-engines, the fly-wheel must be made considerably heavier in the case of gas-engines, even when other conditions are alike. In order to obtain small dimensions of the fly-wheel, nothing is so advantageous as to use either double-acting or multi-cylinder engines, and, above all, to run the engine at a high number of revolutions.

It is also desirable to obtain high explosion-pressure and low final expansion-pressure. Rapid combustion is therefore desirable, and this makes the ignition apparatus, as well as the character of the gas, of great importance. As we shall find later on, it is of the very greatest importance to employ high compression-pressure, *i.e.* small compression-space.

As can easily be seen by the figure, the area **A C D E F B A** represents the work done by the gas on the piston during the expansion stroke, and the difference between the areas **R G C A R** and **L R B L** (**R** is that point where the compression-curve cuts the atmospheric line **AB**, and **G** that where the exhaust- and the compression-curves cut each other) represents that work which, during the compression, has to be overcome by the fly-wheel of the engine. Consequently, the useful work during these two strokes is represented by the area **L R G C D E F L**. During the exhaust stroke, a work **F G S A B F** and, during the suction stroke, a work **A H L B A** must also be overcome, from which it is evident that the area **F G S A H L F** constitutes a non-efficient work, representing the pump-work required. The difference between these two areas, **L R G C D E F L** and **F G S A H L F**, will thus constitute a measure of the indicated work. As, however, the area **L R G F L** is common to both these areas, it can equally well be said that the indicated work is given by the difference between the areas **G C D E F G** and **L R G S A H L**. The area enclosed by the lines of the card shows here, too, as in the case of the steam-engine, the indicated work. The difference is merely that, in the case of the four-stroke engine, the indicator card consists of two different areas, the smaller of which must be subtracted from the larger. In fig. 34 these two areas are shaded.

As, however, the indicator springs, which have to be employed with the high pressures which occur, are altogether too stiff to be able to show the real amount of the negative work with any degree of accuracy, this work is either often neglected, or it is indicated separately by the help of weak springs, in which case the indicator-piston is provided with a stopper. Without this precaution the weak spring would, of course, be destroyed.

As the inlet- and exhaust-valves act only at every other revolution, it will be understood that the valve-motion cannot be brought about by the crank-shaft, but that an extra shaft must be arranged for the

purpose. This so-called *lay-shaft*, or *cam-shaft*, is driven by means of common gear-wheels or spiral gear-wheels, in the proportion 1:2, *i.e.* with half the number of the revolutions of the crank-shaft.

### The Two-Stroke Cycle.

It has long been considered a defect in the four-stroke cycle that only every fourth stroke is a working stroke, and, therefore, an effort has been made to alter the working so that, as in the case of the steam-engine, the piston should get a power-impulse for every revolution. As was shown by what has been said in the foregoing section, the engine, in the case of a four-stroke cycle, acts as a pump during the first and fourth strokes. It is clear that this part of the cycle can, however, be turned over to a special pump-cylinder, which in this case can, together with the apparatus belonging to it, be built considerably lighter and simpler than the working cylinder, and with less friction-resistance. In this case only compression and expansion take place in the working cylinder, and the desired end is thereby attained. The price of this, however, is an extra cylinder, an extra piston, connecting-rod, *etc.* Thus, regarded as a whole, the engine can scarcely be considered as simpler; on the contrary, in some cases, as more delicate. It can be advantageous sometimes, however, to employ such an arrangement.

In the case of small engines, the crank-case is usually turned into a pump, in which case the upper side of the piston serves as the working-piston and the under side as the pump-piston. We shall return to the constructions employed in such cases when we come to describe the various types of engines.

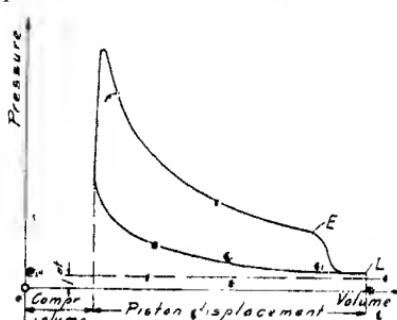


FIG. 35.

Fig. 35 shows an indicator card of a two-stroke engine. When, during its expansion stroke, the piston reaches **E**, there are opened either narrow ports in the walls of the cylinder or valves in the head, after which the pressure suddenly sinks to a fraction of 1 atm. above atmospheric pressure.

As soon as the pressure has sunk so far, there are opened, at a later position of the piston, other ports or valves through which the charge, or the air respectively, streams into the cylinder. In this process the greatest possible effort should be made to get the fresh charge, or air, respectively, to push the gases which are already burned, in front of it without mixing with these latter. Then, when the piston has reached the dead centre **L**, it returns, after which compression begins

as soon as the ports or valves have been closed. In other respects the compression, combustion, and expansion take place as in a four-stroke engine.

### The Six-Stroke Cycle.

When, in the case of the four-stroke cycle, the working piston has completed its fourth stroke and is at the dead centre A (fig. 34), it has driven out of the cylinder a volume of burned gases — BA. But, on the other hand, the whole of the compression-space MK is filled with such inert gases. The charge which is drawn in with the next stroke becomes, therefore, diluted with these remainders, and so the combustion is impaired.

For this reason some English designers have put two extra pump-strokes between the fourth and the first strokes. During the fifth stroke the piston draws in fresh air, and during the sixth it drives this out again. When the cycle once more begins, the compression-space is filled with pure air, which, of course, is of advantage for the combustion of the gas afterwards drawn in. By this arrangement the power of the engine has been diminished, however, and extra friction-work has been introduced. On account of these and other inconveniences, such engines are of little account at the present time, especially as the size of the compression-space and, consequently, of the amount of gas that remains, becomes smaller and smaller the higher the compression is driven. Now, a considerably higher compression-pressure is employed than was the case when the six-stroke cycle began to be employed, so that there are no, or very few, engines now built that work on this principle.

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We sometimes hear engines spoken of as built on the *one-stroke cycle system*. By this is meant an engine which gets one power-impulse during every stroke. A two-stroke engine with two single-acting or one double-acting cylinder is, therefore, a one-stroke engine. According to this method of speaking, a four-stroke engine, with four single-acting cylinders, would thus become a one-stroke engine. By employing still more cylinders one could get *half-stroke*, *quarter-stroke engines*, etc. In my opinion these titles are exceedingly misleading, and should never be employed. As the expressions "two-stroke" and "four-stroke" are now usually employed, they express the nature of the cycle that takes place in the cylinder of the engine. But an engine built in accordance with the one system is subject to quite other conditions and other principles of design, and is even sometimes confined to quite other kinds of work than an engine built in accordance with the other system. The expressions, "one—" and "half-stroke," however, say nothing about all that. They express only the number of working strokes per revolution; but this is of very little use in judging an engine, since it is by no means an unimportant matter whether an

engine works with, for example, eight single-acting four-stroke, or with two double-acting two-stroke cylinders.

## II. CONSTANT-PRESSURE ENGINES.

This working-method has gained importance through the invention of the *Diesel motor*. The piston draws in pure air and compresses it to high pressure (125-140 lbs. per square inch). After reaching the dead centre, there is injected (by means of air still more highly compressed) liquid fuel, which is finely divided in the cylinder, and, by means of the high temperature produced by the compression, is ignited and burned. The construction of the fuel-admission valve causes the combustion to take place at a comparatively constant pressure. After this the expansion begins, and, finally, the exhaust gases are expelled during the fourth stroke. The indicator

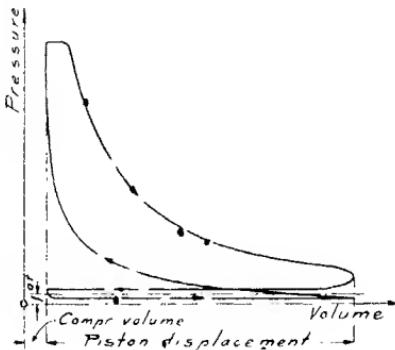


FIG. 36.

card (fig. 36) has, it will be seen, a resemblance to that of a steam-engine. It is clear that this system can also be combined with the two-stroke.

The first person to use the constant-pressure cycle was the American *Brayton*, who, in 1874, constructed petrol-engines in accordance with this cycle. His engine was very imperfect, however, and no use was made in it of compression-ignition. The constant-pressure method, however, can only be made use of for liquid fuels. All gas-engines, on the contrary, work by explosion—that is, by combustion at constant or comparatively constant volume.

Oil-engines working on the constant-pressure cycle are, in practice, somewhat more advantageous from a thermal point of view than good explosion engines. The reason for this lies partly with the nature of the cycle, but mostly with the better combustion, the smaller losses caused by cooling, the comparatively small compression-space, and the consequent better scavenging.

## CHAPTER II.

### GAS-ENGINES.

#### I. GENERAL DESCRIPTION.

WHEN engines working on a new principle first appear in the market, the different makes show, as a rule, many important variations from each other. This is quite natural, as at first there are always certain difficulties that have to be overcome. Even if the end in view stands out clearly and distinctly, different designers try to reach it in different ways. Combustion engines, during the comparatively short time they have been on the market, have undergone a very chequered course of development. The great number of patents taken out when a new industry comes into existence also contributes to still further accentuate the differences. But the older an industry becomes, the clearer is seen the way that must be followed in order to reach the desired end in the best and simplest way. Even now, gas-engines are beginning to arrange themselves into groups, in each of which the types are fairly similar. The greatest differences are those existing in the engines intended to burn cheap oils. On the whole, this condition of things indicates that gas-engines already fulfil every reasonable demand, but that, as a rule, this is not the case as regards oil-engines, or not to such a high degree, at least. We do not wish to deny, of course, that much remains to be done in the domain of gas-engines.

That which chiefly necessitates the great difference in construction between a steam-engine and a gas-engine is, first of all, the high temperatures, and also the high pressures, that are employed in the case of the latter engines. The chief consideration as regards the steam-engine is, as is well known, to do everything possible to prevent the cylinder from cooling. That phrase of Watt's, "Keep the cylinder just as warm as the live steam," still holds good to-day. In the case of combustion engines, on the other hand, we have to deal with temperatures that rise to about 3500° F. When, therefore, such enormous temperatures are allowed to act on surfaces which must continually glide upon each other, it is at once evident that an effective cooling becomes a matter of the very greatest importance. It is true that cooling implies a carrying-off of heat—in other words,

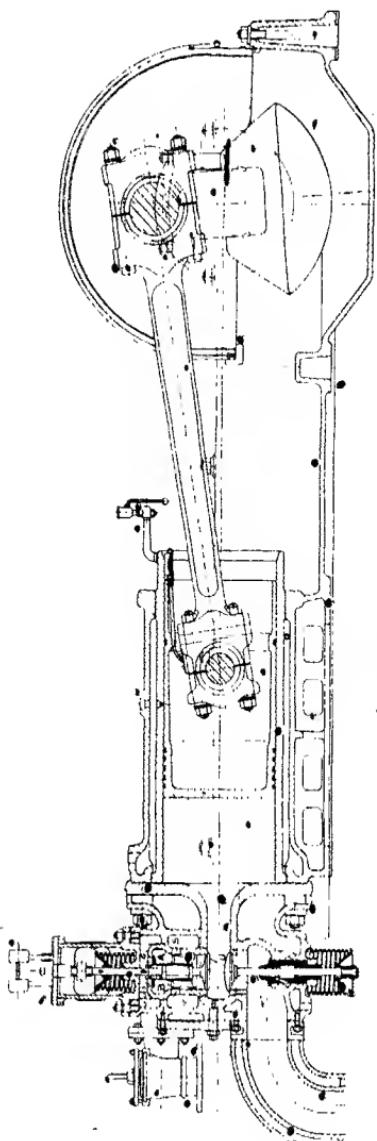


Fig. 37.—Gasmotorenfabrik Deutz.

of energy—but this is a loss we cannot escape from. In order to always be sure that the water washes over all the parts that require cooling, it should always have its outlet at the highest point of the cooling jacket. It need not be said that it is not enough merely to lead in water, but that care must be taken to obtain a good and even circulation, and for this reason it is often necessary to employ cast ribs, or some other device, for the purpose of leading the water along proper channels.

The high pressures necessitate the most central method of construction possible. In the case of gas-engines, therefore, we find as a rule the double-column construction of the frame, as shown in fig. 37. The connecting rod engages in a crank shaft which is journaled on each side of it, with the bearings drawn as close to each other as possible. The two bearings are in a powerfully built frame, which is cast in one piece with the cooling-jacket wall. The inner cylinder-barrel, on the other hand, is a separate casting. This arrangement has the great advantage that it can be cast of harder and more durable iron, and that, when worn out, it can easily be changed for a new one without its being

necessary to renew any other part of the engine. In addition to this, the inner barrel can freely expand in a longitudinal direction without giving rise to any so-called "heat-stresses." Care must be taken, of course, that good packing is provided against the cooling water—a matter of no very great difficulty, however. In the case of small engines, this arrangement would be too detailed, so that for such engines the inner cylinder barrel is cast in one piece with the jacket wall.

In the further end of the cylinder is the cylinder-head, which has been developed in the combustion-chamber, and has also been provided with valve-chambers.

A great inconvenience attending gas-engines, which is altogether absent in the case of steam-engines, is that the gas is not pure, whether producer-gas or blast-furnace gas be employed. Even the air which is sucked in from without is far from pure, compared with the steam when it comes direct from the boiler.

A part of the dust that comes into the cylinder when gas which is not very well purified is used, mixes with the lubricating oil and forms a hard crust, which is anything but beneficial to the durability of the cylinder and of the piston, and may give rise to pre-ignitions and other disturbances in the working. The valves especially may be prevented from closing at the right time, in consequence of the dust fastening on the seat and stem of the valves. Even on the valves of the supply pipes, which are opened and closed by hand, the dust fastens if there is too large a proportion of it in the gas, the valves thereby getting difficult to move. *Damp* gas acts specially unfavourably, as damp dust naturally fastens more easily than dry on the surfaces with which it comes into contact. During a *stoppage* especially, the damp dust dries into a hard crust which, under unfavourable conditions, may make the valves stick, and so make it impossible to start the engine. For the necessary proportions of purity of the gas the reader is referred to p. 46.

In order to facilitate the removal of dust during the exhaust stroke, the exhaust-valve **U** is, in large engines, generally placed as far down in the cylinder as possible (cf. fig. 86). In contrast to this, some few other firms that build large gas-engines place the exhaust-valves at the top, or at the side, of the cylinder. This is for practical reasons. In such cases, however, the lower part of the cylinder is provided with a special blow-out valve, which either is opened only now and then by hand, or else is operated from the cam-shaft of the engine, so that it is opened a moment during each compression stroke. In such a case, the burnt oil and the dust is blown out through this valve. Such blow-out valves are often used with ordinary gas-engines, too—in which case, however, they are opened only every now and then by hand.

The most natural position for the inlet-valve **V** will now be directly over the exhaust-valve, as in fig. 37, and the further advantage is thereby gained that at each suction stroke the exhaust-valve is cooled

by the cold charge which flows into the cylinder, and over and around the valve.

In the construction shown there is fastened to the stem of the inlet-valve a combined gas-valve **A** and an air slide-valve **B**, the so-called mixing valve. When the inlet-valve **B** is opened by its cam, the mixing valve is also carried downwards, thereby opening both the gas-canal **G** and the air-ports **S** in the valve-chamber, the size of which is so proportioned to the area of the gas-valve that the gas and the air can be drawn into the cylinder in suitable proportion. To make the gas-valve keep tight and to prevent valve-breakage, it is not fastened firmly to the inlet-valve, but is kept pressed upwards by a spring, and is carried downwards by a cotter as shown in the figure.

It may as well be pointed out at once that a proper proportion between the amounts of air and gas sucked in is a chief condition for the good working of the engine. It is clear that the construction just described ought to guarantee the carrying-out of this condition as long as the air and the gas, which are taken in through separate pipes, are always exposed to the same pressure. Such is not the case, however, partly in consequence of variable resistance in producers and cleaning apparatus, partly in consequence of the inertia of the great masses of air and gas which are set in motion at every suction stroke. In order, however, to keep the pressure as constant as possible at the intakes, valves are provided which can be regulated by the engineer, so that a proper proportion between the gas and the air can be preserved during varying working conditions.

Finally, in fig. 37, there is shown how the exhaust gas, after having passed its valve, is led off through a pipe which is kept water-cooled. This should always be done in the case of better kinds of installations, as an unpleasant radiation of heat into the engine-room is thereby prevented. For it must be remembered that the exhaust gases, as a rule, have a temperature of about 750° F. The water-cooling of the pipe contributes to cooling the exhaust gases, and thereby to deaden the noise they make on escaping, as well as to lessen the resistance to the piston during the exhaust stroke. This remark applies more to small engines, however, where the cooling surface of the pipe is large in proportion to the volume of the gases.

Water is sometimes injected into the exhaust-pipe, in order thereby to cool the exhaust gases in a simple and effective manner. If, as is often the case, however, these contain sulphur compounds, such as sulphur dioxide,  $SO_2$ , which, oxidised, forms sulphuric acid, such an arrangement cannot be employed, as otherwise the pipes would be corroded.

Just between the valves sits the electric igniter, to which we shall return later on.

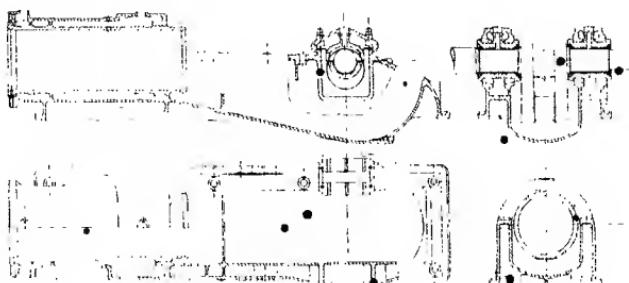
The valve-motion is brought about, in all small and medium-sized engines, by means of cams, secured to a cam-shaft, or lay-shaft, running along the frame. This shaft is driven direct from the crank-shaft by means of a worm-wheel gearing running in oil.

## II. THE VARIOUS PARTS OF THE ENGINE.

## The Engine-Bed and the Cylinder.

The Engine-bed consists, as a rule, of cast-iron, although other materials are sometimes employed, such as cast-steel in the case of large engines, and aluminium alloy or phosphor-bronze for automobile motors.

Figs. 38-41 show the engine-bed of a horizontal engine of very powerful construction. The frame is elevated as much as possible, so that the forces acting in the bearings—which, in the case of explosion engines, come to a considerable amount—can be received direct and centrally by the engine-frame. Many types of engines are very badly designed in this respect. In order to locate the centre of gravity of the side beams as near as possible to the forces acting on the bearings, and thereby to diminish as much as is feasible, the tensile



Figs. 38-41.—Engine-bed (Nydgqvist & Holm).

stresses caused by the bending, the upper horizontal part of the side beams are considerably thicker than the vertical walls (see fig. 41). For the same reason the vertical walls of large engines are usually made of increasing thickness upwards.

The Bearings are usually lined with some white alloy. Bronze shells are sometimes employed.

In the case of large engines, where a hot bearing could cause great inconvenience, the bearing-shells are sometimes given a spherical form, and then the bearings can adapt themselves to the deflection of the crank-shaft. The water-cooling of the bearings, too, is of great importance, and has been employed even in the case of small, high-speed marine engines of automobile-motor type.

The Cylinder.—In the case of smaller-sized engines, the inside barrel is generally cast in one piece with the jacket-wall; in the larger ones it is made as a loose liner. An indispensable condition is that the working-surface of the cylinder shall be quite tight and smooth and without blisters or porous places. This condition is, of

course, more easily carried out if the inner barrel is cast separately (see p. 110). Very large gas-engine cylinders are cast either in one piece with the jacket-wall (fig. 86), or else they are put together of several parts (see fig. 93). Attempts have also been made to divide large cylinders in the middle, and to provide loose liners, in much the same way as in an air-pump of a condenser. Good results have been obtained with such constructions in spite of the poor cooling action which one would suppose to exist in such a case.

The material is cast-iron, except in the case of certain automobile motors for racing purposes, where the cylinders on some rare occasions are made of steel. In the United States *air-furnace cast-iron* (i.e. cast-iron smelted in the reverberatory furnace), is often used for cylinders, pistons, etc. Such castings are poorer in graphite than the ordinary ones, and—on account of the smaller amount of gases in the iron—considerably more homogeneous, and show a strength which can be as much as 50 per cent. more than that of ordinary cast-iron.

The **Cylinder-Head**.—In this is enclosed the greater part of the *combustion-chamber*, and it is therefore plain that its walls are exposed to exceedingly high temperatures. Here, then, the form it will have, as determined with reference to the water-cooling and durability, will be a most important factor. In the event of the loss of heat arising from the water-cooling being the only determining factor, an attempt would be made, in any case, to get the least possible cooling surface. The body which, with a given volume, has the least surface is, as is known, the sphere, and therefore this ought to be determinative of the form of the compression-chamber. For constructive and other reasons, we are obliged, however, to depart more or less from this form.

It is also plain that, in the case of engines that compress pure air, and in which the fuel is not introduced into the cylinder before the end of the compression, there can be no inconveniences but only advantages associated with small cooling surfaces. But, on the other hand, this is not always the case with gas-engines. As we shall find later on (p. 261), a high compression is the first condition for obtaining a good effect. But, with the rising compression, the temperature of the charge rises too, and, simultaneously, the danger of *pre-ignitions* (see p. 282). It has now been proved that, especially in the case of large engines, a better economy is obtained by not keeping so strictly to the endeavour to obtain small cooling surfaces, but, instead, to work with higher compression. For this reason, certain firms arrange in the combustion-chamber extra cooling surfaces, for the purpose of thereby reducing the temperature during the compression period. An example of this is shown in fig. 80. It is clear that a considerable amount of heat is carried off by this arrangement during the expansion stroke, too; but, as, we have said, it has also been proved that the result of the compromise—if it is not carried out to excess, of course,—appears as a gain.

In the case of horizontal engines, the construction shown in fig. 37.

has, as a rule, been retained. Fig. 42, however, shows a different design.

In the construction in question the inlet-valve is opened early towards the close of the exhaust stroke. But it is so arranged that at first only the air-inlet is opened, while the gas-piping is kept closed. On account of the inertia of the exhaust gas which streams out, a vacuum arises in the cylinder towards the end of the exhaust stroke when the piston diminishes its speed. The air now forces its way through the inlet-valve into the combustion-chamber, and pushes the exhaust gases before it, which thus pass off through the exhaust-valve. It is clear that, under favourable circumstances, such as with long and straight exhaust-piping and with a suitable number of revolutions, a far better scavenging than usual can be obtained in this way. This idea was originated by *Atkinson*, and is shown to be, in many cases, very serviceable. It is evident, however, that this arrangement demands an exact, practical knowledge of the dimensions of the piping, as, of course, the effect is dependent on the momentum of the exhaust gas. We can, thus, only calculate on any gain in those cases when the engine works with a speed which does not vary too much. Should, on the other hand, the piping not be suitable in size, it is clear that we run the risk of the exhaust gas forcing its way into the air-piping, in which case there will be a loss instead of a gain.

In the construction shown in fig. 37, this method of acting cannot be employed, as, of course, the air from the inlet-valve would only pass direct downwards and out through the exhaust-valve, without acting on the gases which are in the other part of the compression-chamber.

The material is commonly cast-iron. Cast-steel is sometimes used for large engines, and aluminium alloy for automobile and flying-machine motors.

The **preservation of a tight joint** between the cylinder and the head is brought about either by grinding the surfaces against each other or by means of a gasket consisting of some heat-resisting material, as, for example, asbestos-packing, clingerite, etc. The packing is often put into a groove in the cylinder, which confers the advantage that the packing cannot be blown out by the high pressure. Of late years a packing consisting of asbestos, and surrounded at the edges by a thin copper shell, has been used a good deal. In general it should be observed that in order to get a tight joint, it is neither necessary

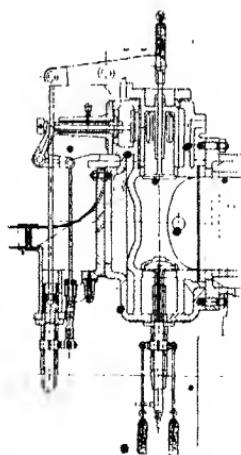


Fig. 42.  
(R. Hornsby & Sons.)

nor suitable to employ thick packing. On the contrary, a thin packing is better and does not necessitate tightening up the bolts too far.

### Power-Transmitting Parts.

The **Piston** is, as a rule, made of cast-iron. It is only in the case of very large engines in which the piston is carried by the piston-rod that cast-steel is used sometimes. If it is necessary to employ this material, the piston should be annealed, in order to avoid foundry strains and to obtain a fine grain. The piston is exposed to very varying temperatures, as the temperature in the cylinder during the expansion stroke varies from  $270^{\circ}$ – $360^{\circ}$  F. down to  $750^{\circ}$  F. While the working-surface of the piston cannot be reached by these high temperatures, the piston-face is, on the other hand, directly exposed to them, and it therefore becomes a matter of great importance to arrange for the best possible cooling. In the case of horizontal four-stroke engines, the outer air has free entrance to the interior of the piston, and, in consequence of the reciprocating motion, a very good air-cooling is obtained. In two-stroke engines with compression of the scavenging air in the crank-chamber, fresh air, too, comes in at every revolution, and this gives the necessary cooling. With vertical high-speed four-stroke engines, in which the crank-chamber is completely enclosed, the ventilation is, on the other hand, often very poor, and air-temperatures of  $150^{\circ}$ – $180^{\circ}$  F. are by no means rare. In general, such engines would benefit greatly by better arrangements in this respect.

As the face of the piston is more exposed to heat than the part situated farther from the combustion-chamber, it expands more. This unequal expansion is compensated by making the piston slightly tapered towards the top. Although it would, undoubtedly, be the best practice to let the piston prevent the leakage of gases only, and to leave it to a special cross-head to take care of the side pressure from the connecting rod, this construction is very seldom found in smaller-sized engines. For the sake of economy, the piston is made to perform both these functions, and is therefore extra-long. The length is very seldom less than the diameter of the cylinder, but is sometimes  $2\frac{1}{4}$  times as long. Within certain limits it may be said that the longer the piston is, the more durable the engine. Larger pistons are usually water-cooled (figs. 80 and 86).

The **Piston-Pin** is made of steel, and is ground and hardened. In the case of trunk-pistons, the pin, on account of its built-in position, forms one of the most delicate parts of the engine, surrounded as it is on every side by surfaces radiating heat. In addition to this, the lubrication of this important part of the engine is, in many instances, carried out in a very primitive manner.

The character of the **Piston-Rings** is also of great importance. Their task is to reduce the loss through leakage to a minimum. It is therefore requisite for them to rest with a certain pressure against

the cylinder-wall, but with no greater pressure than is necessary, as otherwise the cylinder would be worn out before its time, in addition to reducing the power of the engine. As a rule the piston is packed with spring-rings of cast-iron, which are forced over the piston and into the grooves cut round it. The rings should be made of soft tenacious cast-iron, and should be softer than the cylinder, in order to diminish the wear of the latter.

The piston-rings are often made somewhat broad, which is an error, however; narrow packing-rings move better along the cylinder-wall, and allow of a larger number of rings being put in, whereby the packing-pressure per unit area can be kept lower, which naturally acts favourably on the wear of both cylinder and rings. Nowadays, it is often the custom to hammer the rings on the inner side, in order thereby to increase their elasticity.

It is also of great importance to remove dirt from the grooves, so that the rings can move freely. As it is never entirely possible to prevent oil burning fast in the grooves, it is a wise step to lubricate the piston with a mixture of equal parts of oil and petroleum once a week for a couple of hours before the engine is stopped. The petroleum dissolves the products of combustion, whereby the rings are kept readily movable in their grooves.

By means of dowels, the rings are given such a position that their joints do not lie in the same line. If they did, considerably increased leakage would occur. On taking out the piston for cleaning, care should be taken to see that these dowels have not loosened.

The **Crank-Shaft** in all better kinds of engines is made of steel. In the case of large engines and of automobile motors, nickel-steel is used (with about 3 per cent. nickel) or sometimes even chromium nickel-steel or vanadium-steel. The latter materials are employed only when extra lightness is required.

The dimensions of the crank-shafts of combustion engines are considerably larger than in steam-engines, depending on the high pressure employed in the former. By boring out, the weight of the shaft can, however, be diminished. When the Diesel motors first appeared, circulating cooling water was led through the hollow shaft in order to keep the crank-pin bearing cool, but this method was soon abandoned. The crank-pins are sometimes hardened.

The **Connecting Rod** is, as a rule, made of soft steel or cast-steel. In the case of automobile motors (especially with certain French types) the rod was formerly made of cast-iron, for the connecting rod is chiefly exposed to compressive stresses to which this material offers great resistance.

#### The Valves.

The function of the valves is to introduce and provide an exit for the gases from the engine, and they are thus exposed to the high temperatures prevailing in the cylinder. In spite of this they are expected to keep tight, and to act well. As regards the inlet-valve,

every time it opens it comes into contact with the cold gases which stream in. The exhaust-valve is worse off, and so must be ground oftener. On this account it was, until a short time ago, a common practice to water-cool the exhaust-valves of large engines. Of late, however, uncooled valves have come more into use, and nowadays not even the valve-seat is always cooled (see fig. 87). Fig. 37 shows the appearance of ordinary uncooled valves, while fig. 43 shows a water-cooled valve. The arrows indicate the direction taken by the cooling water.

As, on opening the exhaust-valve, there prevails in the cylinder a pressure of from 25 to 60 lbs. per square inch, the back-lash effect on the valve-gear from an ordinary valve will be considerable. For this reason, almost as in steam-engines, double-seated valves have been tried, but the device has not justified expectations. The question of the employment of such valves cannot, however, be regarded as thus decided, as the design used was not unimpeachable in every respect.

Attempts have been made to replace disc-valves by slide-valves, but the results have not been very encouraging. It can, however, be considered as pretty certain that it would be possible to produce practicable and suitable slide-valves, but the construction would probably be rather intricate. For a special design see p. 247.

On the other hand, the idea of balancing the valves, as shown in figs. 44 and 133, is probably a good one, under certain conditions. Still, the fact must not be disregarded that the balancing valve considerably increases the acceleration pressure and frictional resistance which the valve-gear has to overcome. The design in question should be used with discernment, therefore, and in difficult cases, with high-speed engines, it is better to provide each cylinder with two or three exhaust-valves.

Fig. 43.  
(Ehhardt &  
Schmer.)

In the case of smaller engines, automatic inlet-valves are often used, opened by the vacuum arising in the cylinder during the suction stroke. In most cases, such engines show a low volumetric efficiency, the result of the valve not closing in time, in consequence of its inertia. The piston thus has time, during the beginning of the compression stroke, to drive back a part of the gas that was sucked in during the previous stroke. If we examine such engines, we usually find, however, that their bad method of working is, in great measure, to be ascribed to their unnecessarily clumsy form, and also to the fact that the valves often are insufficiently guided. If such valves are made of the best material, and of slender dimensions, the inconveniences just mentioned will be very small, even with a high number of revolutions. On the other hand, the most vulnerable point is, un-



doubtedly, that an impact occurs each time the valve opens. By providing a hard steel spring, acting as a cushion, between the valve-guide and the stopper, the shocks can, however, be greatly diminished. Still, it is clear that there can never be a question of employing automatic valves with other than small engines. One consideration in the design is that such valves shall always be placed vertically, with the valve-disc downwards; for, as can easily be seen, it is only then that the valve-spring can be so adjusted that the valve remains almost hanging, so to speak. If, on the contrary, the valve be placed with the valve-disc upwards and the stem downwards, the weight and the spring-force will act in the same direction.

If, from a smaller engine—where, as a rule, the cooling of the valve is little attended to—the exhaust-pipe be quickly removed

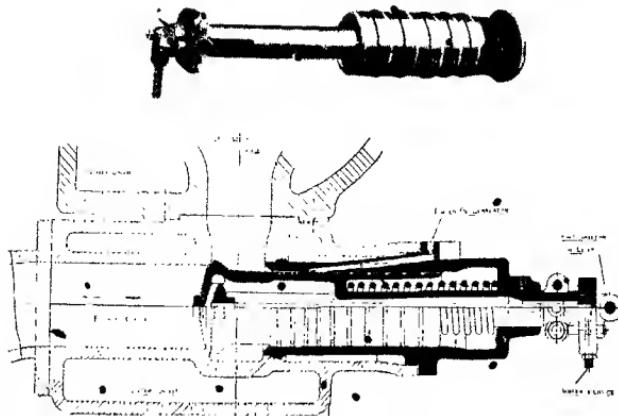


FIG. 44. (Crossley Bros., Ltd.)

while the engine is in motion, we shall find that the stem of the exhaust-valve is red-hot. It is, therefore, often best not to lubricate it; but if this be done in the case of larger engines, neither grease nor oil must be used, for then the stem will stick fast. Petroleum, with the addition of a little oil or vaseline, can, perhaps, be employed, for petroleum evaporates at high temperatures, and it also possesses the useful property of dissolving dirt. Care should, however, be taken that such lubrication is carried out before the engine is started. No lubrication at all should be done when the engine is in motion, as, otherwise, burnt oil easily collects on the hot stems. Water-cooled valves naturally form exceptions to this rule.

Automatic valves are usually provided with flat, but other valves with conical, seats.

The material is cast-iron or steel for the valve-disc, and steel for the stem. Valve-discs of bronze have also been tried, being cast in

one piece with the stem. Nowadays, a 25 to 35 per cent. nickel-steel is often used, as valves made of this metal neither rust nor warp so easily as others. In this case the stem is, however, made of high-carbon steel to resist wear, and is electrically welded to the disc.

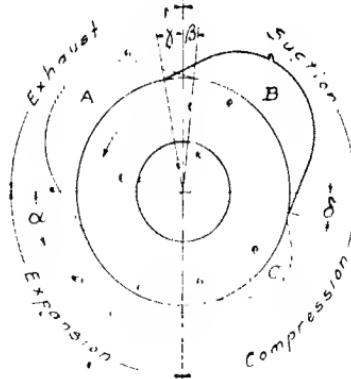


FIG. 45.

to each other. **A** is the exhaust-valve cam; **B** the inlet-valve cam, and **C** the cam used to lower the compression when starting the engine. When the valves are closed, there must be a small clearance, either between the cam and its roller or between some other parts of the valve-gear. This clearance should be carefully maintained, as a small alteration will often cause a remarkable change in the valve-setting.

The valve-setting depends largely on the speed of the engine.

Let  $\alpha$  denote the angle at which the exhaust-valve opens,

“  $\beta$  ” ” ” closes,

“  $\gamma$  ” ” ” inlet-valve opens, ”

“  $\delta$  ” ” ” ” closes,

all these angles being measured on the *cam-shaft circle* and from the dead centres as shown in fig. 45. Some values are given below as used in practice.

TABLE XII.

| Angles on<br>Cam-shaft<br>Circle. | Stationary<br>Engines. | Motor-car and Marine<br>Engines. |   |
|-----------------------------------|------------------------|----------------------------------|---|
| $\alpha$                          | 15° to 23°             | 15° to 30°                       | The - sign<br>signifies that<br>the valve<br>opens at the<br>angle given,<br>after the<br>crank has<br>passed its<br>dead centre. |
| $\beta$                           | 5° to 10°              | 0° to 9°                         |   |
| $\gamma$                          | 8° to 12°              | -( $\beta + 2°$ ) to -2° to -11° |   |
| $\delta$                          | 10°                    | 0° to 25°                        |   |

### Ignition Systems.

On the reliability of ignition depends the entire successful working of the engine. If the ignition fails, the engine stops; if the ignition works fairly well, the engine will work, it is true, but only fairly well, too. The ignition is, so to say, the heart of the engine. The first ignition device attempted was that one which most naturally presented itself:

**Ignition by External Flame.**—In its simplest form this arrangement consisted of two different flames, of which the one, *the igniting jet*, lit the gas in the cylinder, while the other—the so-called *auxiliary jet*—served to relight the igniting jet which was put out at every ignition of the gas. One of the oldest of these constructions was *Barnet's*, in which the igniting jet was inside a rotating valve which was provided with an opening. The latter, at every revolution, left a free passage for the igniting jet, which was thereby alternately put in communication, first with the gas mixture in the cylinder, and secondly with the auxiliary jet outside the cylinder. The device acted pretty well up to forty ignitions per minute, but was attended by the great inconvenience that gas was let out every time the two burners were put in communication with each other. Neither was the ignition reliable if it was exposed to wind, for if the jets were put out, the engine, of course, stopped. Ignition arrangements in accordance with this principle in which the rotating valve was exchanged for a slide-valve, and which were afterwards still further improved, afforded greater reliability of working, and made it possible to increase the number of ignitions to over 100 per minute. Such engines exist to-day even, in some places, and work satisfactorily. As, however, all these devices—although they were in their day considered as very remarkable—are never used nowadays for new engines, it would be useless to describe them any further.

**Ignition by Internal Flame.**—In the Brayton engine mentioned on p. 108, the gas was ignited by a continuously burning flame inside the combustion-chamber. The device could, of course, only be employed in engines in which the gas was introduced into the cylinder immediately before ignition. In order to prevent the flame from blowing back, which would have occasioned an explosion in the gas-tank, a fine wire-gauze was placed behind it. Still, there was always the danger of the working being interrupted, and this ignition device was also soon superseded.

**Ignition by Catalysis.**—If incandescent platinum or spongy platinum be exposed to a stream of gas, it will remain incandescent; and if the speed of the gas be increased, the temperature of the platinum becomes so high that the gas is ignited. This peculiar characteristic of platinum has been made use of in the case of gas-engines, but the system had the inconvenience that the ignition was not reliable, nor did it permit of an adjustment of the ignition-moment.

**Ignition by Hot Tube.**—This ignition device which, in its day, was

much spoken about, and is still employed with smaller engines, consists of a porcelain, platinum, iron, or nickel tube in communication with the cylinder. This is the so-called *hot tube* which is kept heated to incandescence by means of an external flame. After each expansion stroke, waste gases remain in the tube and are, during the latter part of the compression stroke, compressed so much that the fresh charge can force its way to the hottest part of the tube, where it is ignited by the hot walls. A flame then rushes out of the tube and into the cylinder, and ignites the whole of the gas mixture there present.

In order to adjust the moment of ignition, an attempt has been made to use a *timing valve*, in combination with the hot tube. In the canal connecting the hot tube with the cylinder there was put a valve which did not permit of communication between the hot tube and the cylinder until just before the piston began its "return" stroke.

As these valves used to stick, however, and did not keep tight, and rusted, the plan has, in general, been adopted of adjusting the ignition by altering the position of the external heating jet. The construction in question is still used, however, although on a small scale.

Fig. 46 shows an ignition tube. The moment for ignition depends not only on the length of the tube and the size of the canal in the cylinder, but also on the size of the tube, its position on the cylinder, the degree of compression, the temperature of the tube, the character of the surfaces

of the tube, the position of the external flame, the temperature of the cooling water, the load and speed of the engine, the gas mixture, and the method of governing, etc.

We thus find that the moment of ignition is dependent on quite a number of circumstances, some of which bear a relation to the construction of the engine, and thus can be ascertained experimentally. Others, again, are related to the character of the engine for the moment, and thus are almost entirely incapable of being controlled. The result is that ignition by hot tube is only employed for small engines, where reliability of action is not so much considered as a low first cost.

**Ignition by Hot Bulb (or Hot Pot).**—This system of ignition is shown in fig. 115, and has been largely employed for oil-engines. In comparison with the hot tube just described, which is specially sensitive to outer influences, the hot bulb is far more capable of resistance to such injurious factors. It is true that it sometimes

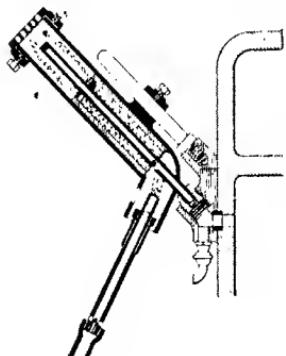


FIG. 46.

bursts, or is destroyed by the great heat, but there is no great expense incurred in replacing it.

At first sight it would seem peculiar that an equable running of the engine can be obtained at all by means of such a simple ignition device, and several fanciful hypotheses have been made in the endeavour to find an explanation. The fact has been neglected that, in many hot-bulb engines, the ignition does not occur with such very great regularity, but that, on the contrary, both pre-ignitions and late ignitions occur alternately, when the load or the speed is altered; and, above all, it has been overlooked that an engine provided with hot bulb requires, as a rule, more careful attention on the part of the engineer than is the case with engines provided with modern, highly developed electrical ignition.

Before the engine is started, the hot bulb is heated by means of a blow-torch. When the bulb has been heated to cherry-red, oil is introduced, by means of suction or pressure in the case of four-stroke, and by means of pressure in the case of two-stroke engines. The engine-shaft is then moved backwards and forwards a few times so that compression arises. By this process the vapourised oil is mixed with air in the bulb, and ignites against the hot walls of the latter, after which the engine starts. After some minutes' running the lamp is put out. The bulb is often surrounded by a shell which partially prevents the radiation of heat. By the help of the heat produced in the cylinder by the explosions, the bulb afterwards keeps sufficiently hot without special heating from without, which is a great advantage compared with the igniting tube. In most engines of this kind a certain quantity of cooling water is introduced into the cylinder along with the combustion air, this amount being sometimes as much as 50 per cent. of the amount of oil; and this, other conditions being equal, permits of the employment of a higher compression-pressure.

In order to understand the method of working of the hot bulb, it is of importance to know under what conditions an engine provided with this ignition works satisfactorily, and when it does not. It has now been shown that hot-bulb engines work best when they are allowed to run at a constant speed and with constant load—or, in other words, if the heating conditions of the hot bulb remain unaltered. If, on the other hand, the load be increased, the engine will often slow down, on account of the temperature of the bulb rising too much. "The engine gets too hot," is the common expression; but it will be evident that the engine itself does not become too hot, as there is no difficulty in water-cooling the cylinder sufficiently for all loads. The high temperature of the bulb expresses itself chiefly by the ignition taking place too early, *i.e.* pre-ignition arises, whereby the speed of the engine is, of course, diminished. It can even happen that the ignitions occur so early that the engine either stops entirely or is reversed, and starts moving in the opposite direction. But in some cases the engine can go slower for another

reason; for, in the event of oil being used as fuel (which is usually the case with hot-bulb engines), the "gasification" of the fuel takes place by means of the oil being injected into the incandescent bulb either during the exhaust-, suction-, or compression-stroke. Now, if the bulb be of the right temperature, the oil is immediately gasified; but if the temperature be too high, or the sprayer be out of order, a part of the oil is coked. As thus, in the latter case, only a part of the fuel is utilised, the speed of the engine is consequently diminished—that is, unless the governor does not allow of the introduction of a corresponding amount of oil. Besides this, pre-ignitions are easily produced by deposits of carbon which keep incandescent. In order, in such a case, to be able to keep the engine running, the attendant has no other resource than to increase the injection of water into the cylinder, or to cool the bulb in some other way, i.e. to bring the bulb to the temperature formerly prevailing. If, on the other hand, the load of the engine is to be diminished, the injection of water must also be diminished, or the temperature of the bulb kept at the right height in some other way. Otherwise the engine comes altogether to a standstill.

One of the so-called theories—which is no theory but merely an hypothesis—which has been put forward in order to explain the method of working of the hot bulb, is that of *Guldner*,<sup>1</sup> and his assertions are reproduced (but incorrectly) in German technical literature as facts. In his explanation, *Guldner* starts by saying that the canal between the bulb and the cylinder is usually of small dimensions. It is true there are good reasons for this, but they have little to do with the fundamental idea of the ignition bulb. His explanation is briefly as follows:—

During the compression stroke the piston drives an ignitable gas mixture before it into the bulb, where the gas is *immediately* ignited by the glowing walls. The burning gas now endeavours to force its way into the cylinder again through the narrow canal. As, however, the area of the canal in question is small, the gas or air which streams through it into the bulb, and is driven onwards by the piston, acquires a greater velocity than that with which the jet burning inside the bulb endeavours to blow back. It is not before the speed of propagation of the igniting jet, in the neighbourhood of the dead centre, exceeds that of the stream of gas or air that the flame can rush into the cylinder. This is the main feature of *Guldner's* explanation, by the help of which all the peculiarities of these engines can be explained. It is, of course, a very clever and simple one, and it has only one fault—which is, that it is wrong. That this is so is shown most simply by an engine having been found in which the whole of the hot bulb, a consequence of bad combustion, had coked together with a hard crust of carbon deposits, but which engine, in spite of all, continued to work.<sup>2</sup>

<sup>1</sup> *Entwerfen und Berechnen der Verbrennungsmotoren*, 2nd ed., p. 120.

<sup>2</sup> *Teknisk Tidskrift*, part 41, 1908.

It is an old-established fact that it is possible in this manner to prevent the onward movement of a heat-wave, but, unfortunately, it is not possible to thus control the ignition of engines with ignition bulbs.

The fundamental idea of all ignition is to develop, at one point at least in the gas mixture, so high a temperature that a local combustion is there begun which is afterwards allowed to communicate itself by some means to the rest of the gas. Now, the ignition bulb acts like all other ignition devices, by making the gas nearest to its walls so hot that it ignites. The bulb, however, must not be kept so hot that ignition takes place until just before the dead centre. Now, it is to be observed that the temperature of the charge rises not only on account of the radiation of heat from the bulb, but for another reason also. During the compression stroke the pressure is increased constantly, and with the increase of pressure follows a corresponding increase of temperature. Towards the end of the compression stroke, especially, both the pressure and the temperature rise very rapidly (see card, fig. 31). In a certain position of the piston it now happens that the total of the increases in temperature which are derived, partly from the radiation of heat from the bulb, and partly from the increase in pressure, becomes so great that ignition takes place of the gas lying nearest to the wall of the bulb, after which the combustion is carried on to the rest of the gas. The bulb must thus be made so thick, and in other dimensions be made in such a way, that it can acquire a suitable temperature for causing an ignition immediately before the dead centre. It is clear, from what has been said, that the dimensions of the bulb depend on the amount of the compression-pressure and the number of revolutions of the engine.

It might be supposed that, under these circumstances, the moment of ignition would incessantly alter. This is the case, too, with ignition-bulb engines of ordinary construction; but this variation is kept within fairly narrow limits, as the compression curve in the indicator card, and with this the increase in temperature produced by the compression, just in the vicinity of that position of the piston where the ignition is to take place, rise very rapidly. If, thus, the temperature of the bulb is for any reason increased, a lesser compression temperature is required for ignition to take place; but a relatively small alteration in the position of the piston corresponds to this alteration in the compression temperature. The engine has thus a possibility, in a certain degree, of regulating itself.

In the case of greater changes, either in the load or the speed of the engine, this automatic regulation, however, will not be sufficient. If, for example, the engine works for a long time at maximum load, the bulb will be inclined to get very hot, which is counteracted in a very simple way, by an increase in the injection of water. The engineer adjusts a cock, or, with some engines, matters are so arranged that the amount of water injected stands in a fixed proportion to the

amount of oil. Both the amount of oil and of water are measured off in such a case by the same gear. In the latter case regulation by hand is also arranged for.

On account of the whole nature of the ignition, it is clear that little contingencies of many kinds will have a certain influence. In practice it has been shown that the water-injections required by two engines which have been built according to the same patterns and drawings often vary from each other. On the other hand, there are engines which have neither water-injection nor any other means for regulating the bulb, and yet, in spite of this, can work even at no load. Certain engines, on the other hand, stop at about half load; but, in general, hot-bulb engines are more sensitive to variations in speed than to changes in the load.

What has been said above refers chiefly to engines of ordinary construction, where the oil is injected relatively early into the bulb. There are other engines, however, in which the injection is not undertaken before the dead centre is nearly reached. With these engines the difficulty with pre-ignition disappears almost entirely, as compression takes place on pure air. On the other hand, the difficulty remains with the over-heating of the bulb, for which reason the injection of water is often retained.

**Ignition by means of electrically heated Metal.**—In order to escape from the inconveniences attached to ignition by means of a burning jet, attempts were made at an early period to employ an electric current for heating an isolated platinum coil which was fastened on a slide and introduced into the cylinder when ignition was to take place. As the use of such fragile platinum wires was a very unsatisfactory method, however, and also on account of other inconveniences attending this method, these devices have, nowadays, totally disappeared, and have made room for the following.

**Electrical Ignition Systems.**—If rightly employed, electric ignition is the most reliable of all methods, with the exception of the automatic ignition employed with the *Diesel motors*. The great advantages of electrical ignition may briefly be stated thus:—

By its help the moment for ignition can be altered at will, and thus the ignition can be brought about almost anywhere in the combustion-chamber, and without danger of fire. A burning lamp in an open boat in windy weather is, of course, not such a very harmless resource; but there cannot possibly be any danger in an electric spark within a closed cylinder. In addition to this, an engine with electric ignition is always ready for starting.

The following are some of the essential points with regard to electric ignition:—

The igniter should always have such a position in the cylinder that, at the moment of ignition, it is surrounded by ignitable gases. This is attained most easily if it is placed in the way of the charge that streams into the cylinder. It should, therefore, not be placed in "pockets" or other out-of-the-way places, because it is in such places

that burned gases chiefly collect. Besides this, it ought to be possible for the flash to communicate by the shortest possible path with all the parts of the combustion-chamber. From the point of view of ignition, therefore, the ideal would be a spherical compression-chamber with the igniter in the centre.

A very good position for the igniter is centrally above the piston. In the case of small engines, which are lubricated by the connecting rod's dipping in oil, it sometimes happens, however, that the oil finds its way up between the piston and the walls of the cylinder, after which the oil can be splashed up by the piston on to the igniter, which, in such a case, might easily cease to act. This happens especially when the face of the piston is bulged downwards, and it is therefore often found preferable to put the igniter centrally above the inlet-valve, when it is certain, too, of always being surrounded by ignitable gases. In the case of large engines, double igniters are usually employed, partly to ensure ignition and partly to make the explosion quicker.

For the ignition these are employed either a single spark or a stream of sparks, and the different ignition devices used can be divided into two different systems, each embracing many modifications.

#### A. The Electric Current is obtained from an Exterior Source.

This is the oldest and the simplest method, and it is still widely employed. As source of current use is made either of batteries or of accumulators, or else, if electric power can be had, the current may be taken direct from the mains. So-called *dry batteries* are used with advantage for automobile or motor-boat engines. The difference between these and ordinary batteries is that, unlike the latter, they do not contain the electrolyte concentrated, but mixed with a mass — sawdust, for example — to a jelly, which has the property of retaining the moisture a long time. The advantage of batteries is, of course, that they do not possess any movable parts, and that they can be placed anywhere. Dry batteries are especially convenient, because there is never any danger of the liquid being splashed out if the battery be exposed to shaking. On the other hand, they suffer from the inconvenience that their electro-motive force disappears by degrees. Common cell-batteries can, in such a case, be refilled very easily, and the accumulator be recharged, while the dry battery must be exchanged for a new one.

What has been said above shows the importance of never exposing dry batteries to direct sunlight or heat, as then they soon dry. In strong sunlight it can even happen that the liquid forces its way out of the batteries. They should also be protected against severe cold (below 5° F.), for the electrolyte of the battery consists of ammonium chloride, which at low temperatures crystallises out of the sawdust, thereby greatly increasing the interior resistance of the battery. The best method of procedure is to bind the batteries round with

woollen cloth, and to put them into a wooden box. If this box be provided with as many compartments as there are batteries, they are then well protected against short-circuiting. If the weather be specially cold, the batteries can, if necessary, be thawed over a stove. As soon as they have begun to work, they keep themselves sufficiently warm by means of the heat from the chemical reaction.

- The weak current from the battery, which should have a tension of 4 to 6 volts, must, before being used, be transformed up to a high-tension current. For this purpose an induction coil is employed, from which the current is led, by means of a well-insulated wire, direct to the igniter, the so-called *sparking plug*.

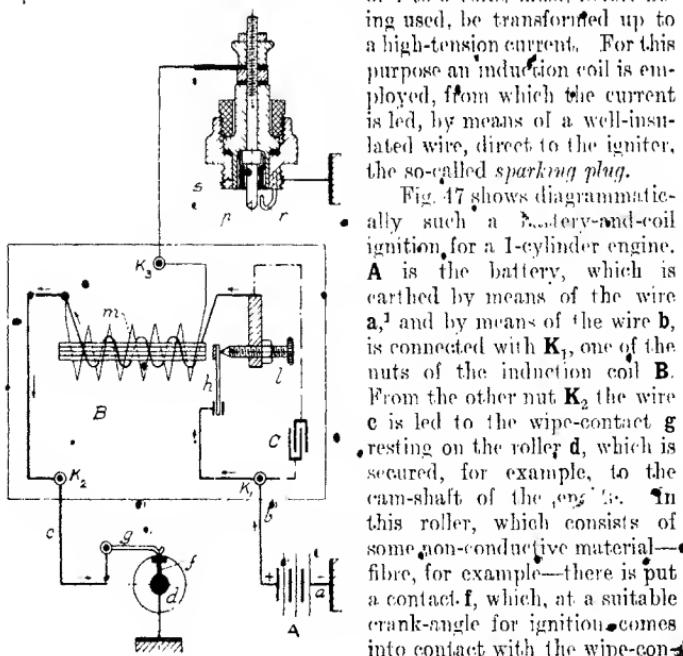


FIG. 475

electrically connected with the shaft, it is clear that, as soon as *f* and *g* form a contact with each other, the primary circuit from the battery will be closed, as its two terminals are earthed. In the figure *h* marks the vibrator or trembler, and *I* the contact screw. *C* is the condenser. The primary circuit is marked by heavy, and the secondary one by thin, lines. For the method of working of induction coils the reader is referred to text-books on electricity.

After **f** and **g** have formed contact, the trembler **h** begins to vibrate very rapidly, whereby secondary currents of such high voltage are

<sup>1</sup> In order to be able to open and close the circuit, a switch should be provided, which is not, however, shown in the figure.

induced in the thinner winding **m** of the coil that sparks jump over at the sparking plug, from **p** to **r**. This latter is connected with the finer winding of the induction coil by means of the cable **t** and the nut **K<sub>3</sub>**.

The **sparking plug** (fig. 47), which is also called the **ignition plug**, consists, in principle, of two electric poles at some distance from each other, of which **p** is connected with the wire **t**, while **r**, together with the outer part of the plug, is screwed into the cylinder-head, *i.e.* is earthed. The poles consist of nickel, platinum, or other metal, and are isolated from each other by means of porcelain, mica, porstone, or similar materials.

The **sparking plug** ought to be kept very clean, but emery-cloth should not be used for the purpose, as otherwise the smooth surface of the plug would be injured, and dust would only the more easily attach itself to it. Ordinary dirt is best taken away by washing the **sparking plug** with petrol. If oil has come on it, however, **oil** has burned fast, is not always possible to get the plug clean in this way; but, in this case, it can be rubbed with a bit of wood which has been dipped into acid. After the porcelain has regained its white colour, the **sparking plug** should be well-washed, so that no acid is left. Attention should be called to the fact that the **sparking plug** will not afterwards act until it has become perfectly dry. The reason that the **sparking plug** is so sensitive to dirt is that the oil that comes on to the contact-points might prevent the gas from coming into communication with the spark, and it is difficult, too, for the current—unless it is specially strong—to jump over. Oil which has burned fast promotes the deposition of electrically conducting substances, whereby the **sparking plug** may be short-circuited.

**induction Coils** of two kinds are used, *viz.* either with or without a **trembler**. As these apparatus are often of French manufacture, it might be useful to explain the letters occurring on them, as these point out how the different wires are to be connected to the nuts near the letters.

|          |                       |  |
|----------|-----------------------|--|
| <b>B</b> | <i>means Bougie</i>   | = Sparking plug.                                   |
| <b>M</b> | <i>„ Masse</i>        | = Earth.   |
| <b>P</b> | <i>„ Pile</i>         | = Battery.   |
| <b>A</b> | <i>„ Accumulateur</i> | = Accumulator (storage battery).                   |
| <b>C</b> | <i>„ Contact</i>      | = Contact ( <i>e.g.</i> contact on the cam-shaft). |

Fig. 48 shows a contact-breaker for a 4-cylinder engine, intended to work together with an induction coil *without* a trembler. With four-stroke engines it is arranged on some shaft which is driven with half the number of revolutions of the crank-shaft. In the case of two-stroke engines, on the other hand, the shaft in question must rotate as fast as the crank-shaft. Fig. 49 shows a similar contact-breaker for an induction coil *with* a trembler.

In using non-trembler coils, it is of great importance that the

contact-springs, shown in fig. 48, should quickly move away from the corresponding contact-screws. The cam which actuates the springs has, therefore, as a rule, such a form that only the one direction of rotation can be employed with any degree of reliability. In the case of trembler coils on the other hand, the primary current remains closed a longer time, so that a series of sparks is obtained at the sparking plug.

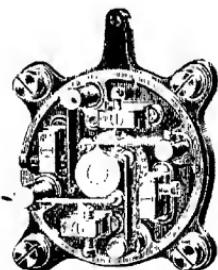


FIG. 48.

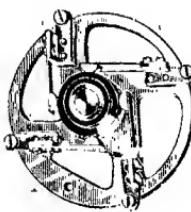
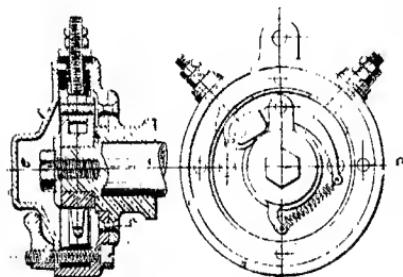


FIG. 49.

Non-trembler coils seem to have the advantage in point of simplicity, as they have no movable parts, but this is neutralised by the greater delicacy of the contact-breaker on the cam-shaft. In addition to this, the ignition that works with a trembler cannot get its batteries discharged so easily as one of the other kind; for if, on account of the negligence of the attendant, the ignition is switched on when the engine stands still, this is perceived in the case of trembler apparatus being used, by the buzzing noise that a properly working trembler makes.

Figs. 50 and 51 show a contact-breaker, that is much employed.



FIGS. 50 AND 51.

The contact-roller, which rotates with the shaft, is pressed by means of a little spring outwards towards the segment-shaped contact-pieces, which are insulated and in connection with the nuts of the induction coil. The contact-roller is electrically connected with the shaft, *i.e.* is earthed. The illustration shows an apparatus for a 2-cylinder engine, but, of course, the construction can be used with any number of cylinders. Its great advantage is that the contacts lie perfectly enclosed. The interior of the contact-breaker should, however, be sometimes lubricated

construction can be used with any number of cylinders. Its great advantage is that the contacts lie perfectly enclosed. The interior of the contact-breaker should, however, be sometimes lubricated

with a few drops of oil or a little grease. It is doubtful, however, whether ignition, with a roller contact such as this, always takes place at the same crank-angle.

Fig. 52 shows diagrammatically the wiring of a 2-cylinder engine with battery ignition and non-trembler induction coil, while fig. 53 shows the wiring diagram for a 4-cylinder engine in the event of a trembler induction coil being used.

As is seen, with a 4-cylinder engine there is also used a quadrupole induction coil. As, however, this latter is the dearest part of the whole ignition, a modified arrangement is sometimes employed. In the system in question, which was invented by *Gianoli*, use is made of a single induction coil, however great the number of cylinders may be. The end is attained in a very simple manner by distributing the

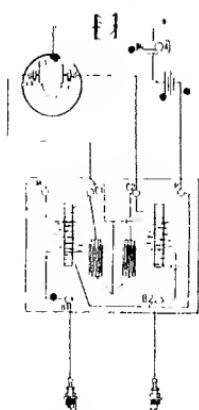


FIG. 52.

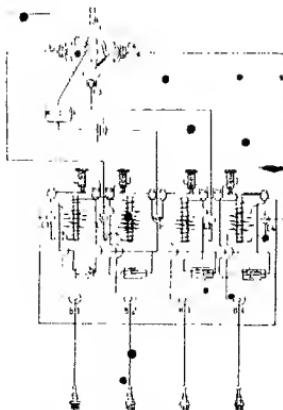


FIG. 53.

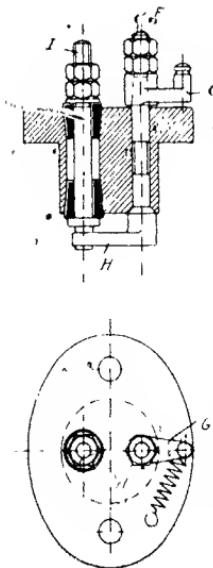
current in the secondary circuit amongst the different sparking plugs—a method, however, which is attended with an unpleasant formation of sparks at the high-tension distributor.

The above-described system of ignition consists, then, in the transformation of a primary current from a fixed source of current into a high-tension one, and that in this secondary circuit there exists a break sufficiently large to permit of the current continuing its path by forming sparks. From this it is clear that it is very important for the distance between the points of the sparking plug to be neither too small nor too large. If the points are too near each other, the spark will not be of sufficient intensity; and if the distance is too great, the current will not be able to break the resistance of the air, and so there will be no spark. A suitable distance between the points is usually found to be  $\frac{1}{16}$  to  $\frac{1}{8}$  of an inch.

**Make-and-break ignition** works without secondary circuit. In

the case of this ignition, use has been made of the well-known fact that if a closed electric circuit is suddenly broken, a spark will arise at the point of breakage and continue until the distance, and thus, too, the resistance, becomes too large. If such a breakage of the circuit can take place within the cylinder at such a place that the spark is surrounded by the charge, this will evidently be all that is necessary.

Figs. 54 and 55 show the so-called *igniter*. In the flange itself, which is of steel, are inserted two points, **I** and **F**. The one, **I**, is rigid, and is insulated from the flange by means of tôle, porcelain, or mica, but is connected with the source of current by means of a wire. The other point, **F**, is not insulated, and is movable within the flange.



Figs. 54 and 55.

In the case of multiple-cylinder engines, the plan is highly recommended of providing the wire to each single igniter with a switch. If the ignition fails, the trouble can then be discovered more easily. It is clear that the different igniters must be connected in parallel.

Formerly the movable lever **H** was provided at the point at which it rests against the pin **I** with a little flat piece of platinum, which, however, on account of the shocks, could not be got to stick fast. Nowadays, the points **I** and **F** are made entirely of chrome-nickel steel, and so the inconvenience mentioned disappears.

The hammer-break gear is, of course, made in different ways, according to the construction of the engine. With high-speed engines care should be taken to make the movable parts as light as possible and to use sufficiently strong springs. One way of arranging the breaking of the current is described on p. 137 and fig. 59. The igniter

is there shown in connection with a magneto, but the hammer-break gear can, of course, be used together with any other source of current that may be desired.

There are some inconveniences, however, with this system likewise. In case of bad combustion soot is very easily deposited on the electrodes, and, it being difficult for the current to pass such a deposit, the ignition can easily fail when the points are removed from each other. There can also be a short circuit if the insulated electrode is earthed by being covered with some substance which is a conductor of electricity. In that case, when the points are moved away from each other, the current takes the path of least resistance, and so there will be no spark. If the engine is very cold, it will often be found of advantage to take out the igniter before starting and warm it. In the case of suction-gas plants this may be done by letting it be a moment on the producer. Otherwise the steam of the charge will be condensed on coming into contact with the cold igniter, or water, brought in with the compressed air used for starting, may short-circuit the points. It will then be impossible to start the engine, or it will stop again after some few revolutions.

In order to escape the inconveniences caused by soot on the points, attempts have been made to bring about a sliding movement between the lever **H** and the point **I**—a problem which it is very difficult to solve in a satisfactory way, however. In order to give the spark greater intensity, an induction coil without trembler is usually inserted in the circuit. The coil acts as a condenser.

**The Lodge Ignition** may be considered as an improved form of the ordinary battery-and-coil ignition using a sparking plug. Essentially it consists of a battery delivering current of low tension to an induction coil and two Leyden jars, which transform it into a current of high tension and high frequency. This secondary current causes a spark to be formed at the sparking plug. The ignition is timed in the low-tension circuit by a wipe-contact on the cam-shaft.

The battery **A** (fig. 56) consists of a common 6- to 8-volt accumulator, which, in order to avoid recharging, in electric plants may be connected through lamps to the electric supply mains. The low-tension current from the battery passes through the induction coil **B** with its condenser **C** as usual, and is timed by the insulated wipe-contact brushes **D** and **E** on the cam-shaft. Once every revolution the two brushes are electrically connected by an insulated contact-piece in the ring **F**.<sup>1</sup>

So far, the arrangement is about the same as in the ordinary battery-and-coil ignition. The secondary winding is not, however, connected to the sparking plug **G** directly, but to the inner coatings of two Leyden jars **H** and **K**, as well as to the terminals of a spark gap **L**. The outer

<sup>1</sup> Two brushes are used instead of one as in fig. 47, so as not to "earth" the electric light mains which happen to be used for charging the accumulators.

coatings of the Leyden jars are, on the other hand, connected by **M** to the sparking plug **G**, and by **N** to earth.

When the primary circuit is closed by the brushes **D** and **E**, the induction coil is set to work in the usual way, thereby causing the current induced in the secondary winding to charge the inner coatings of the Leyden jars **H** and **K** with electricity of equal but opposite potential. At the same time the outer coatings will become charged, equally

but oppositely, both to the inner coatings and to each other, provided that they are connected together. In order to do this, without at the same time short-circuiting the sparking plug **G**, a semi-conductor **P** is used, consisting of damp blotting-paper enclosed in a glass tube to preserve its moisture.

When the jars are fully charged, a spark will jump over at the air-gap **L**, and, if the width of this gap is such that an oscillatory discharge may follow, there will be an exceedingly rapid rise and fall in the potential of the inner and outer ~~coatings~~, thereby causing an alternating current to flow to and fro between the outer coatings of the jars. This current will, on account of its very high frequency, meet with so great apparent resistance (impedance) in the conductor **P** that it will take its way

through the air-gap at the sparking plug instead. For the same reason, the spark thus formed will not be short-circuited by water or carbon and dirt deposits on the plug, which, in other ignition systems, often give rise to trouble. It should be pointed out that this is so because the oscillations of the discharge at the sparking plug are so extremely rapid. With an alternating current of lower frequency the case would be quite different.

Fig. 57 shows the high-tension connections in case two sparking plugs,  $G_1$  and  $G_2$ , are used at the same cylinder end. The current then flows from one terminal of the igniter through one of the sparking plugs, through the metal of the engine, and in through the other sparking plug back to the igniter, the circuit being complete and the

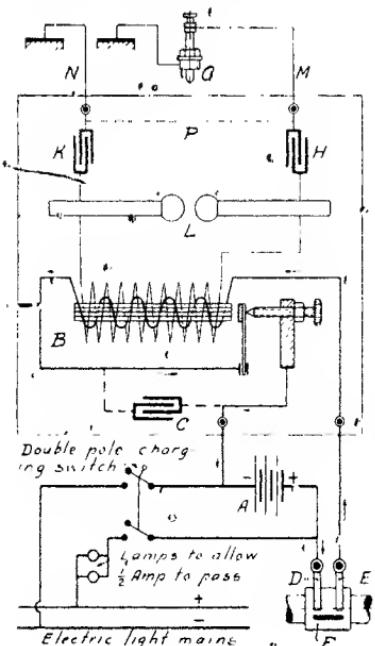


FIGURE 1

two sparking plugs in series. **S** is a two-way switch, by means of which either high-tension terminal, **R** or **T**, can be earthed, thus stopping the one sparking plug or the other from firing.

For a multi-cylinder engine only one igniter is required, in which case a high-tension distributor serves all the cylinders. In large engines it will, however, be found preferable to use one igniter for each cylinder in order to avoid employing the distributor.

#### B. The Electric Current is developed by means of Power from the Engine itself.

In the case of the ignition apparatus just described, the source of energy (except when current from an electric power plant can be had) consisted of batteries or accumulators, *i.e.* use has been made of energy previously accumulated. But such energy becomes exhausted sooner or later. It is true that accumulators can be recharged, but the very fact that new energy must be once more stored is, of course, a great inconvenience. At an early period, therefore, current from a little dynamo was used, which, by means of gearing, was driven from the crank-shaft and gave a current of 10 volts. As, however, battery-ignition was required to start the engine, the plan naturally followed of combining dynamo- and accumulator-ignition in which case the dynamo could, of course, be employed to charge the accumulators and also for lighting purposes at night.

It is, however, a common experience that combinations of machine devices for purposes of different kinds are seldom suitable. This was the case here too, and so arrangements were very soon made for carrying out the ignition as a whole alone. In doing so, use was made of magneto-electrical apparatus of a construction specially devised for the purpose.

#### Make-and-break Ignition with Oscillating Armature or Shield.

Fig. 58 shows a Siemens's I-armature arranged between the poles of a horse-shoe shaped steel magnet. If the armature is rotated between the poles, there arises in the winding of the armature an alternating current which, twice during one revolution, reaches its maximum, and twice goes down to zero. If the one pole of the winding is connected with the electrode **I** (fig. 54) while the other pole is earthed, and if the electrodes **I** and **H** are suddenly separated from each other

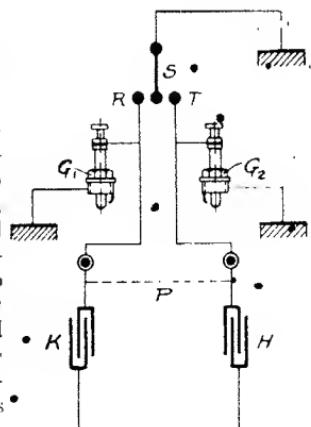


FIG. 57.

at the moment when the armature current has reached its maximum, it is clear that a strong spark or arc light will be obtained. The device is here the same as that described in A; the difference is merely that the battery is exchanged for a dynamo.

In the case of stationary engines, there is used the arrangement shown in fig. 58, in which the dynamo armature A is stationary, and, instead, a hollow cylinder, B, the shield, arranged between the armature and the pole-shoes of the magnets, swings to and fro around that position in which the current reaches its highest value. In order to make the intensity of the spark independent of the speed of the engine, a spring is used to bring about the breaking of the current. As is seen by the figure, the shield is moved out of its middle position by a pick-blade fastened on to the cam-shaft of the engine, and by this means, and at the same time, a couple of powerful springs are made

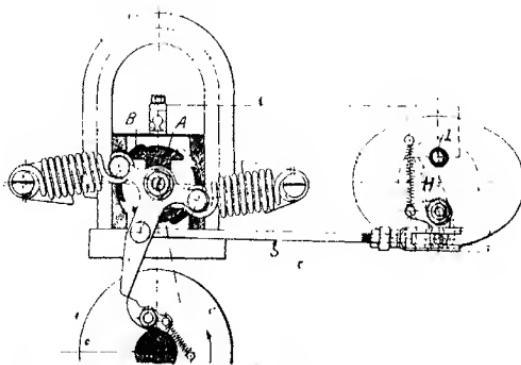


FIG. 58.

tense. These springs being so arranged that they tend to keep the shield in its neutral position, they will pull the shield back with great speed as soon as it is disengaged. With the sudden rotation there is developed a strong current in the armature winding. But, in order at the same time to develop the spark in the cylinder, a rod S is connected both with the shield and with the movable electrode. The connection with the electrode can be so adjusted that the ignition contacts are separated just at the moment when the tension of the electric current is strongest. At the severing of this contact, there is produced in the cylinder a powerful spark which ignites the gas charge.

Fig. 59 shows an ignition device according to the system just described, but with a different construction of the details. The armature is rotated backwards and forwards by means of a lever K secured to one end of the armature. On the opposite end there is arranged a clamp, from which the wire D is led to the fixed electrode. To the lever K is attached the rod M, which, at the one end, is connected

with the lever **R** by means of the lever **N** and a shaft journalled in the frame. At its other end the rod **M** is acted on by a couple of strong springs placed in the cover **L**. The necessary oscillating movement of the armature is brought about by the crank-disc **O**, the rod **P**, and the guide **Q**. The rod **P** is moved up and down by the crank-disc. In order to render it possible to regulate the moment of ignition, the guide **Q** is journalled eccentrically. The arrangement consists in the guide **Q** turning around a pin placed in the hole **U**, which is bored eccentrically in the sleeve **S**, which, in its turn, is journalled in the support of the magneto, and can be set in various positions by means of the lever **V** and the quadrant **T**.

The plate **O** is driven from the cam-shaft. Just before every ignition, the lever **R** is engaged by the upper end **X** of the rod **P**. The armature is hereby rotated through a certain angle, during which the springs in **L** are made tense. When **R** is afterwards disengaged from **X**, the rod **M** is driven rapidly to the left, in which movement a pin projecting from the spring cover strikes the movable electrode **G**.

When a gas-engine is stopped it might happen, however, that, on account of the high compression, it is reversed and makes a few revolutions in the other direction. It will easily be seen that, if **X** and **R** should then engage with each other, one of them would be broken off. In order to prevent this, the guide **Q** is not journalled rigidly, but is free to move in a direction at right angles to the rod **P**. It is kept firmly pressed inwards during normal working by the spring **Z**, and it is pushed outwards only in the case of a reverse movement of the engine, the spring **Z** then being pressed together.

The above-named system, the make-and-break ignition with oscillating armature, is, from a working point of view, one of the best of the electrical ignition systems, and is therefore employed very generally with stationary installations. The spark produced is very intensive, and it can be accurately timed. Against the durability, there is also very little to be remarked. The system has, however, a dangerous rival in the Lodge ignition.

For engines with a high number of revolutions, on the other hand, it is not possible to employ oscillating armature, as the armature will not have come to rest before it would be once



FIG. 59. (Nydqvist & Holm.)

more acted on by the pick-blade. In such cases, therefore, use is made of:—

**Rotating armatures or shields**, with which system the movement for bringing about the breaking of the current is usually derived from a cam on the cam-shaft. As, however, it is attended with inconvenience to allow the winding of the armature to revolve at high speed, the firm of *Bosch*, in certain types of armatures, lets it stand still, and, instead, places, between the armature and the pole-shoes of the magnets, a thin, rotating, sector-shaped shield of soft iron. There is thus produced an alternating current in the winding of the armature, in the same way as before described.



FIG. 60.

Fig. 60<sup>1</sup> shows diagrammatically how the breaking of the current is often arranged in the case of vertical high-speed engines. A weak spring **a** tends to hold the movable electrode **b** against the fixed one **c**. The former electrode is actuated, however, by a vertical rod **d**. This rod, which is pressed downwards by a strong spring, keeps the two electrodes separated from each other, so that no current can be induced in the circuit. Immediately before the moment of ignition, however, a little lever, **f**, is lifted upwards by the cam **n** secured to the cam-shaft. The lever, in its turn, lifts the above-named rod, whereby the movable electrode **b** is released and comes to rest against the fixed one. An electric current is now induced in the wire, and flows through the igniter. Then, when the cam comes into the position shown in the figure, the rod **d** is rapidly pushed downwards, and thereby suddenly separates the two electrodes from each other. A spark is thus produced at the place of breaking, and ignites the charge. The quicker the electrodes can be separated from each other, *i.e.* the more suddenly the breaking of current takes place, the more intensive does the spark become.

As was stated in A, in the case of multi-cylindrical engines, the electrodes must not lie against each other when the ignition is to take place in other cylinders. It is also shown by the figure how, in a very simple way, an alteration in the moment of ignition can be obtained by making the fulcrum of the lever **f**, which is acted upon by the cam, displaceable.

In the case of high-speed engines, however, the movable make-and-break rods occasion certain inconveniences. For one thing, the engine often becomes complicated in consequence, and it is also often necessary to drive the make-and-break gear from a shaft journaled specially for that purpose close to the electrode, in order to keep the mass of the movable parts small. But, in addition to the further

<sup>1</sup> Z. Ver. deutsch. Ing., No. 18, 1906.

complication of the engine which results, it often becomes difficult to secure good lubrication of these parts. These and other inconveniences have caused attempts to be made to do without these reciprocating make-and-break rods.

One method of solving the problem consists in placing a little electro-magnet close to the movable electrode. Every time ignition is to take place, the magnet attracts the electrode, and in this manner breaks the current. This system, which has shown itself quite reliable, is in use in America for stationary engines.

#### The Bosch Magnetic Plug (Honold's System).

A few years ago the firm of Bosch introduced a new construction of the above-mentioned system.

Fig. 61 shows a section through the plug. In a well-cooled part of the cylinder there is screwed in, in the usual way, the nut 1. Inside this latter a contact-piece 2 is suspended on two edges. The one edge projects from the pole-piece 3, and the other from a spring 4, which tends to keep the contact-piece 2 pressed against the other contact 5. Around the central part of the plug is seen the coil 6, which is electrically connected with the shell 7, with the sleeve 8, and, by means of the ring 9, with the nut 10. The nut 1 is insulated from the other parts, but, as it is screwed into the cylinder, the contact 5, which is fastened in the nut, will be earthed. In the pole-piece 3 there are placed a couple of counter-pieces 11 and 12.

With engines of less than 250 ignitions per minute, oscillating armature is employed, except for large engines, the magnetos of which are provided with rotating armature. When the armature is released and, by means of the strong springs (fig. 58), is carried past its neutral position, a powerful current flows through the coil 6 (fig. 61). The pole-piece now attracts the contact 2, thereby suddenly separating its lower part from the contact 5. But, at the same instant, there is formed at the breaking-point a spark which ignites the charge.

For engines running at a high number of revolutions, rotating armature is used, or else stationary armature with rotating shield. As the two contacts 2 and 5 always are in contact with each other, except when the spark is being formed, it is necessary, in the case of multi-cylinder engines, to provide the magneto apparatus with a high-tension distributor which puts only one plug at a time into conductive connection with the armature winding of the magneto.

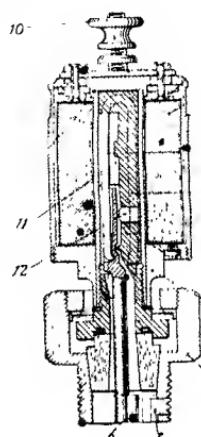


FIG. 61.

The essentially new idea in the construction in question thus consists in the coil being placed centrally around the movable contact, and that this latter is not movable in the ordinary way, but is instead suspended on edges. By means of these alterations it has become possible to so far reduce the dimensions of the sparking plug that it can be screwed into a  $\frac{3}{4}$ -inch gas-tapped hole.

Magneto-electrical systems working with movable sparking plug (also called igniter) employ, compared with such systems as make use of fixed plug, a current of comparatively low tension for the formation of the spark. The former system is, therefore, often called *low-tension ignition*, in contrast with the latter, which has the name of *high-tension ignition*. An example of this latter is

**The Bosch and the Simms Arc-Light Ignition.** The magneto offers the advantage of a source of energy which is always available. The strong side of the fixed electrode, on the other hand, is that it does not require any movable parts at all. It is, therefore, quite natural that an endeavour should have been made to unite both forms in one ignition system. Of such apparatus there are quite a number of different makes in the market, of which the *Bosch* and the *Simms*, which latter is of the same general design, will now be described.

Fig. 62 shows diagrammatically the arrangement of this ignition system, the so-called *arc-light ignition*. The apparatus consists of three chief parts:—

- (1) The current-producer proper.
- (2) The make-and-break gear.
- (3) The high-tension distributor.

As in the former case, a Siemens armature is employed, the wiring consisting of two parts, the primary and the secondary. As

usual, the primary is connected to the iron mass of the armature, and, by means of the wire **B**, stands in connection with the contact-screw **C**, under which is a little earthed lever. The last-named lever is actuated by a cam **E**. The lever **D** is kept pressed by means of a spring against the cam **E**, which is provided with notches in such a way that the lever **D** forms contact

with the screw **C** immediately before ignition is to take place. The condenser **F** is connected in parallel to the breaking-point. The secondary winding is led to the sparking plug as a direct continuation of the primary. When the screw **C** and the lever **D** form contact with each other, the primary circuit is closed, and a powerful

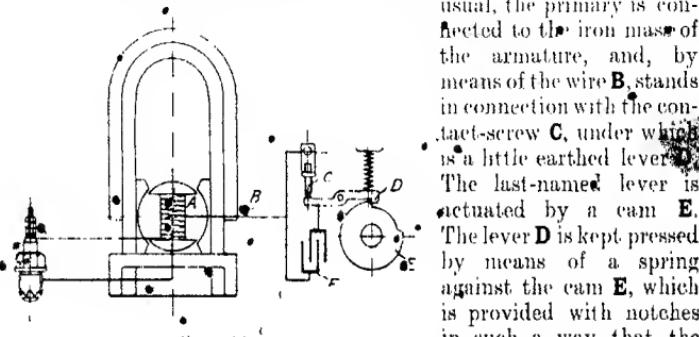


FIG. 62.

current then arises in the same. This current now exercises a reaction on the lines of force which produced it. Then, when, at the moment of ignition, the lever **B** is suddenly separated by the cam **E** from the contact **C**, this reaction ceases—which, in its turn, brings about a rapid alteration in the number of lines of force in the armature. The tension of the current induced in the secondary winding thus becomes so great that a spark is formed between the points of the sparking plug. This spark diminishes the air-resistance so much that the current produced by the rotation of the armature can follow the path formed by the spark, and leap

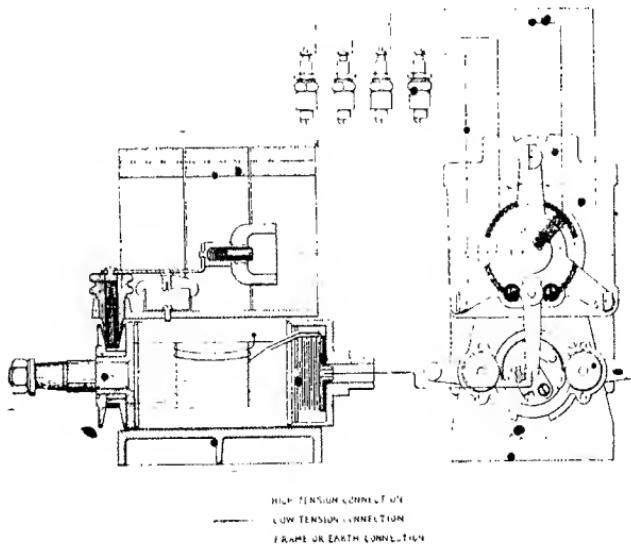


FIG. 63. (The Simms Magneto Co., Ltd.)

over at the plug in the form of an arc light. In a word, the method of working of the apparatus thus depends on a high-tension current developing a spark which, in its turn, forms a kind of bridge, over which a current of lower tension continues. The characteristic feature of this is that both currents have their source in one and the same winding.

The sparks obtained in this manner are of considerably greater intensity than those produced by battery ignition, but cannot, however, compare with those which are obtained with make-and-break ignition.

Fig. 63 shows a section of such an apparatus intended for 4-cylinder automobile motors.

**Dual ignition systems** are also employed, consisting of magneto-

ignition for normal working, and battery-ignition for starting. As a rule, the same sparking plug serves for both ignitions.

It need not be said that the engine stops if ignition ceases. This fact makes it a very simple matter to stop an engine suddenly, and can also be employed in order to obtain security against rating in the event of the governor ceasing to work. For this purpose the engine is provided with a little extra governor which breaks an electric contact in the event of a certain number of revolutions being exceeded.

### Starting Arrangements.

One of the greatest inconveniences with combustion engines is that they cannot be started in so simple a manner as, *e.g.*, the steam-engine. There is here no sort of energy to fall back upon at once, but this must first be produced, or, at least, transformed into a form suitable for starting purposes.

**Starting-Crank.**—Small engines are turned round by hand until a charge is formed and ignition is obtained. But, even in the case of fairly small cylinder-dimensions, compression becomes unpleasantly apparent, and it is, therefore, usual to provide the cylinder with compression release cocks, or to keep the inlet-valve open during a part of the compression stroke by means of a special starting-cam. In this manner the compression can be so far reduced that starting by hand becomes possible, even in the case of fairly large engines. As we have said, the simplest method is to swing the fly-wheel round by hand and, by this means, draw in the charge into the cylinder. But as the fly-wheel, however, is not always very accessible (in the case of automobiles, for example), starting-crank are used instead, which are arranged on the front end of the crank-shaft, and there give a fast hold by means of a claw-like clutch. As soon as the engine starts, the crank releases itself, after which it can be drawn off from the crank-shaft. If, however, the engineer has forgotten to change the ignition to late ignition before starting, the gas can be ignited even before reaching the dead centre. The risk is then run that, on account of its relatively slow speed, the engine will suddenly be reversed, in which case the engineer may easily get his arm or leg broken. The danger of this happening is, of course, greater with engines having hot-tube ignition, where it is not possible to regulate the moment of ignition in a thoroughly reliable manner. In order to render such accidents impossible, a number of so-called safety cranks have been constructed, but they have not been very much used, however. A better method is when the ignition is automatically changed to late ignition, when putting on the starting-crank.

**Ignition of the Gas Charge.**—In order to avoid turning the crank round, which, in the case of large engines, is a matter of much labour, or is absolutely impossible unless special gearing is provided, the method of pumping or sucking in a petrol-gas charge into the

cylinder was early introduced. If the fly-wheel was afterwards turned so much that the crank had passed the inner dead centre, it was then only necessary to switch on the ignition, whereupon the engine started at once. As a petrol-gas charge which is ignited at atmospheric pressure explodes up to 5-8 atm. (70-115 lbs. per square inch), it is clear that a powerful forward impulse is obtained by this method. The engine should be started at no load, however. Large blast-furnace gas-engines, even, have been started in this manner.

Another way sometimes employed is to start the engine by means of a shot. A cartridge is put in the cylinder-head, and then discharged by a contrivance resembling that of a gun. Although this method has been employed with engines up to 110 H.P., it can scarcely be said that it is a very attractive one.

Multi-cylinder petrol-engines can often be started in a very simple way, unless too long a time has elapsed since they were stopped. If, for example, a 1-cylinder petrol- or gas-engine, with the cranks standing at  $180^\circ$ , is stopped by switching off the ignition, one of the pistons will always stop at expansion, with ignitable gas in the cylinder belonging to it. If, beforehand, the engine is unloaded, the crank-shaft will occupy such a position that the gas-pressure on all the pistons will balance each other, this taking place at a crank-angle of about  $90^\circ$ . If, in addition, the contact-breaker is so arranged that it can give late ignitions up to about  $110^\circ$  crank-angle, and if the engine is provided with battery ignition, it is merely necessary to put the ignition crank at "late ignition," after which the engine starts at once. This system can only be employed, however, when the engine has not stood still so long that the gas has leaked out of the cylinders; but, if the valves and the pistons do not leak, a start can be made after a lapse of several hours. The system is fully reliable, however, only with engines with four or more cylinders.

**Starting by Electricity.**—The starting of engines that are used for running electric generators is often a very simple matter, for, if access can be had to storage batteries or to any other source of current, it is only necessary to re-switch the generator, driven by the gas-engine, in such a way that current is led to it from the outer source of current. The generator then acts as a motor. As soon as the gas-engine has started and the ignition has commenced to act, the switch should be reversed, when the dynamo will resume its function as generator. In the case of engines of high power an automatic switch is arranged which breaks the starting-current as soon as the engine has got its first ignitions. The dynamo then works at no load until the engineer has switched it on to the electric mains again. When this method of starting is employed, the cam-shaft of the engine should be provided with special displaceable cams which permit of a lowering of the compression.

**Starting by Means of Compressed Air.**—At a very early date the possibility was seen of using compressed air for starting purposes. For, if a supply of such air is stored beforehand, it is merely necessary

to alter the valve gear in such a way that the engine can work as a compressed-air motor for the first few revolutions, until an ignitable gas mixture is drawn in. Special arrangements are, of course, necessary to produce the compressed air. An air-reservoir is always necessary; but, in the case of small engines, the compressor can be dispensed with. Just before the engine is to be stopped, the fuel-piping is, for this reason, shut off simultaneously with the opening of the pipe between the engine and the reservoir. The engine is now kept in motion for a few revolutions by the fly-wheel, while the pure air which is thus sucked in is compressed, and then pressed in through a non-return valve into the air-reservoir. The cost of this arrangement and of its management is, evidently, very low; but equally, of course, is the inconvenience that we get only a relatively small amount of air at our disposal, so that, if the starting should happen not to succeed, the air is all used up, and there is no possibility of renewing the supply. For this reason, a little compressor, worked by hand, ought always to be available.

In the case of large installations a special air-compressor is arranged, which is driven, independent of the engine, by electricity, by means of an oil-engine, or the like. On the other hand, there is often compressed air available for other purposes, such as for pneumatic tools, etc., and in such a case the simplest plan will be to make use of this. It will often be suitable to arrange the compressor so that it can be driven both from the engine itself and from a special auxiliary engine. As regards pressure, this varies between 6 and 25 atm. (85-350 lbs. per square inch). The use of high pressure has the advantage that the engine can be started with the load on.

In starting the engine the fly-wheel is turned round, either by hand or by means of gear, so that the crank comes some degrees into the expansion stroke. The inlet-pipe for the gas is then opened, after which a valve in the cylinder, and in connection with the air-reservoir, is opened by hand. The air rushes into the cylinder, and, as soon as the piston has begun to move, the engineer shuts the air-valve. The air in the cylinder now expands, at the same time driving the engine round. At the end of the stroke the exhaust-valve is opened as usual. In most cases the fly-wheel has now acquired enough momentum for the blowing-out and the suction and compression of the new charge to take place. The engine gets a further impulse by the ignition which immediately follows, after which the engine continues to work as usual. Although, as we have said, a single filling of air is, as a rule, all that is required, there can be cases when two will be needed. But as, naturally, it is difficult properly to regulate the admission of air into the cylinder after the engine has started, it will be found better to use such a high air-pressure that a single air-filling will be enough. If measures are taken for lowering the compression, and if an air-pressure of at least 110 lbs. is employed, this end will, as a rule, be attained, at least after the engine has been in use for some time, so that it has begun to run easy. In the event

of several air-fillings being necessary, the gas-piping should not be opened before the compressed-air inlet has been closed.

Larger engines have the valve-gear provided with double cams, which are arranged interchangeably on the cam-shaft. Just before the engine is stopped, the engineer seizes the opportunity of throwing the cams used in working out of gear, and to bring over the starting-cams. If he has neglected to do this, however, the fly-wheel must be rotated sufficiently for it to become possible to throw out the cams under the valve-rods belonging to them. The starting-cams are often given such a shape that, when they begin to act, the engine is changed into a compressed-air motor working on the two-stroke cycle. Thus all that has to be done afterwards is to open the intake of the compressed air. The engine then starts at once, and works with air perfectly automatically until the starting-cams are thrown out of gear and the normal valve-gear comes into play. In the event of the engine being multi-cylindrical, it is not absolutely necessary, and, under certain conditions, not even advisable, to provide every cylinder with compressed-air starting-gear. On the other hand, in the case of large engines, it is advantageous to provide so many, at least, of the cylinders with air-valves, that the engine can be started from any position without a prying-over of the fly-wheel being at all necessary. It should be observed, however, that, as a rule, there is no risk of the engine stopping at the dead centre, this being prevented by the high compression. It is clear, however, that there is no absolute security that this will not take place; but, in the event of its happening, it is only necessary to turn the fly-wheel a few degrees forwards. Engines with many cylinders, as, for example, that shown in fig. 91, can, of course, be started in any case from any position, there being no dead centre.

**Starting by Means of Auxiliary, or "Barring," Engine.**—A large engine can be started by coupling to its fly-wheel a smaller engine which can be started by hand. In such a case the larger engine is provided with arrangements for lowering the compression. The auxiliary engine may, if necessary, be employed during the working for lighting purposes, etc. If electric power is available, it is especially suitable.

In the case of large gas-engines, the fly-wheels of which can only be turned with difficulty, use has been made of the electric starting arrangement shown in figs. 61 and 65. An electric motor drives, by means of a flexible coupling, a worm-gearing, which, in its turn, drives, by means of a spur-wheel gearing, a toothed wheel *a* acting on the fly-wheel rim. By the resistance from the fly-wheel the lever *h*, which supports the said toothed wheel, is pressed against a stopper, so that the toothed wheel is kept in a suitable engaging position. As soon as the fly-wheel increases its speed, the pressure on the toothed wheel will act in the opposite direction, thereby throwing the lever *h* to the other side of its neutral position, where it is retained by its own weight. By this disengaging of the toothed wheel *a*, the electric current is also

switched off automatically, and the motor stops. These starting-machines, which, of course, it is desirable to keep as small as possible, are not capable of giving a large gas-engine sufficient speed for starting, but they are employed to drive the engine round when it is being cleaned, and to turn the crank to a suitable position when the engine is to be started by means of compressed air. This position is about 30° past the dead centre on the expansion stroke.

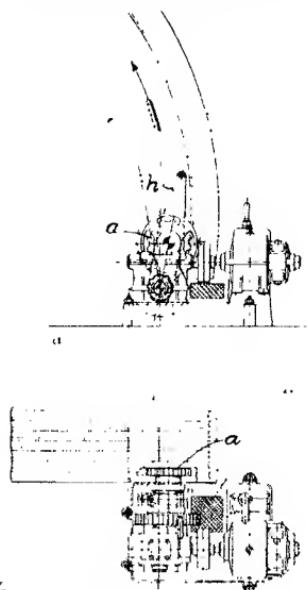
### Cooling.

An indispensable condition for obtaining reliable and economical working with combustion engines is that the cylinder must be adequately cooled, as otherwise the engine not only works wastefully, but it also runs the risk of being destroyed. It is true that, on an average, one-third of the heat which is supplied passes off with the cooling water; but this loss, in modern engines, is, in any case, unavoidable.

The first question that presents itself with regard to the cooling is that respecting the amount and outlet temperature of the cooling water. On the one hand, it is self-evident that the cooler the walls of the cylinder, the more heat is carried off from the gas. From this point of view, then, we ought to be able to expect both greater power and a smaller consumption of fuel the weaker the cooling is, i.e. the warmer the walls of the cylinder are kept. But, on the other hand, the charge is heated during the suction stroke by radiation and conduction from the hot walls of the cylinder, so that a smaller weight of

gas mixture comes into the cylinder the hotter the walls are, i.e. the weaker the cooling is. As, however, it is the weight, and not the volume, of the sucked-in charge which determines the power of the engine, a powerful cooling tends to have a favourable influence in this respect. There are thus two different considerations which are in direct opposition to each other.

As we shall see later on, high compression-pressure is of decisive importance for the economy of the engine. But with high compression there is also a greater tendency to pre-ignition, and this risk is, of



FIGS. 64 and 65.  
(Benzrath Maschinenfabrik.)

course, increased in proportion as the temperature of the walls of the cylinder rises. Here, therefore, we have another weighty reason for employing powerful cooling. Thus, for example, the firm of Koerting places a special cooling box in the combustion-chamber (see fig. 80), in order to be able to increase the compression without danger of pre-ignitions, and by this means good results have been obtained. In a word, the importance which should be ascribed to each of these considerations varies greatly with different engine systems and designs. Large gas-engines require cylinder constructions with relatively larger cooling surfaces than small engines, while, on the contrary, in the case of the Diesel motor, no regard need be paid to pre-ignitions caused by hot cylinder walls, as pure air is here compressed.

The temperature of the cooling water has a great influence on the amount of the frictional losses—i.e. the colder the water, the greater will be the frictional work.<sup>1</sup> In the literature of the subject this fact is put forward without any attempt at an explanation, although one can very easily be given. In the case of engines of the ordinary trunk-piston type, the piston is given a fairly considerable length, and is turned with a diameter which is only slightly less than that of the cylinder—just enough for a proper clearance to be obtained between the piston and the cylinder during normal working conditions. If the cooling is made more effective, so that the temperature of the walls of the cylinder falls, the cylinder naturally contracts, and the clearance is thereby diminished. This, in turn, results in an increase of the frictional work. In the case of engines with long pistons and comparatively small clearance, there often arises—if the temperature of the cooling water is lowered some forty degrees—a dull, low sound, which is a sign that the piston is working hard. But, on the other hand, the cooling must not be too weak either, as in that case there will be trouble with the lubrication. The friction is then increased, and the piston gets hot and scrapes against the walls of the cylinder.

From this we find that the determining factors of this question are, in part, contradicted, and the only thing left is to decide the matter by experiment. In the case of smaller-sized engines, it is the custom to let the cooling water run off with a highest temperature of 160° F. An exception to this is formed by alcohol-engines, which, as a rule, work with a cooling-water temperature of nearly 212° F. In the case of large engines, on the other hand, where the cooling question demands greater attention, the highest outlet temperature of the water allowed is 120° F.

The amount of the cooling water depends, in great measure, on the construction of the engine, the fuel employed, etc. It varies between such wide limits as 22 and 110 lbs. per H.P. per hour. After having decided on a certain increase in jacket-water temperature, the water necessary can easily be computed. Suppose, for example, that in an

See, for example, Schöttler, *Ver. deutsch. Ing.*, No. 25, 1908.

engine running on blast-furnace gas the temperature of the water-jacket is to be raised from  $60^{\circ}$  to  $115^{\circ}$  F., i.e. by  $115^{\circ} - 60^{\circ} = 55^{\circ}$ . Denote by  $y$  lbs. the water needed per B.H.P. per hour. According to Table XVII., on p. 270, the thermal efficiency of an engine of this kind will be about 25 per cent., while 37 per cent. of the heating value of the gas will be carried away with the cooling water. As, further, 2545 B.T.U. per hour correspond to 1 H.P. (p. 271), we get

$$0.37 \cdot \frac{100}{25} \cdot 2545 = 1 \cdot y \cdot 55;$$

$y = 68$  lbs. water per B.H.P. per hour.

The firm of Napier in London has carried out an interesting experiment with one of its automobile motors, the result of which is given here below<sup>1</sup> :—

TABLE XIII.

| Revolutions per minute                              | 1100 | 1100 | 1100 | 1100 | 1100 |
|---|------|------|------|------|------|
| Water-jacket temperature, F.                        | 56   | 115  | 149  | 185  | 212  |
| Diminution in power of engine, per cent.            | 6.6  | 3.6  | 0.0  | 0.7  | 1.0  |
| Increase in consumption of fuel per H.P., per cent. | 19.4 | 8.7  | 0.0  | 2.0  | 1.6  |

As may be seen above, the power was greatest and the consumption of fuel least at a temperature of about  $149^{\circ}$  F. Thus, in the case of the engine in question, this temperature was the most favourable in every respect. On a lowering of the temperature, the engine rapidly deteriorated, while, on the other hand, an increase of the temperature has very little effect. It is, of course, possible that the consumption of fuel increases at  $185^{\circ}$  F., in order to fall again later on; but this appears somewhat peculiar, and, very possibly, may have been caused by some accidental circumstances. One cannot, of course, draw the deduction from these experiments that a temperature of  $149^{\circ}$  F. is the best for other engines too.

It may be taken as a general rule that the cooling water should be supplied to the cylinder from below, and carried off from above. We can then be certain that the water comes into contact with all the heated parts. Still, water is often admitted in the vicinity of the exhaust-valve in order that the latter may secure the greatest amount of cooling possible. If, in such a case, a good circulation can still be obtained, nothing can, of course, be objected to in such an arrangement. In order to obtain a sufficiently good circulation, it is often

<sup>1</sup> The *Automotor Journal*, No. 10, 1903. The table has been computed from the figures given in the account mentioned.

necessary, in the case of large engines, to provide special walls into the cooling-chamber for the purpose of conducting the water. In addition to this, care must be taken that the construction is such that no air-pockets can arise under any circumstances.

In the case of large engines the different parts, such as the cylinder, head, valves, exhaust-pipes, etc., should have separate inlet and outlet pipes for the water, so that the cooling of each special part can be regulated to the most suitable temperature. By this means better control is likewise obtained over the proper circulation of the water. While, for the parts just mentioned, a pressure on the water of about 20-30 feet is quite sufficient, a water-pressure of 40-70 lbs. per square inch is required to counteract the inertia to which the reciprocating water in the piston and piston-rods is exposed, viz., if the water is to pass through only one piston with the piston-rod belonging to it. If, on the other hand, in the case of a tandem-cylinder engine, the same water has to pass through both pistons, a pressure will be required of 4-5 atm. (65-70 lbs. per square inch). If water with such high pressure cannot be got from the mains, a reliable pressure-pump must be arranged, which presses the water through the reciprocating parts. About 25 per cent. of the total amount of water goes, as a rule, to the cooling of the piston. In those cases where there is not a sufficient amount of cooling water, it must be re-cooled and used over again, as in steam-engine plants. By this means the amount of water consumed can be restricted to 4-5 lbs. per B.H.P. per hour. In small plants use is made of ordinary cooling tanks, in which the water is allowed to stand until it has become cooled. In other cases the water is allowed to run over a so-called cooling tower. A very suitable and simple one can be arranged in the case of small engines by erecting a stand in a tank, provided at the top with a ring to which are attached hanging strings. The cooling water is allowed to run down into the tank along the strings, and, on account of the finely divided way in which it runs down, gets cooled by the outer air. From the tank it is then pumped into the engine.

The cooling hitherto taken into consideration is that ordinarily used, viz. cooling by means of circulating water. In the case of small engines, so-called *cooling by evaporation* is sometimes used. The cylinder is then surrounded by stationary water, which is allowed to stand and boil. In consequence of the well-known fact that considerably more heat is required to transform water into steam than to bring the temperature of water to the boiling-point, the amount of water necessary can, by this means, be greatly reduced, sometimes down to as little as 2-5 lbs. water per H.P. per hour.

The purity of the cooling water is a matter of great importance, as mud, etc., easily deposit on the walls, and so impede the carrying off of the heat. In such cases where dirty water must be used—for example, for boats on canals—there ought to be large, easily accessible openings provided in the cylinder and cover, so that cleaning can be easily carried out every now and then. The amount of deposit

increases with the increase of the temperature of the cooling water, but when clean water is used nothing need be feared as long as the temperature of the outlet water is kept below 115° F.

It should also be mentioned that, in the case of automobile motors, cooling by means of air can also take place. We shall return to this later on (see p. 249).

**Utilisation of the Heat of the Cooling Water.**—Instead of arranging special cooling apparatus for the water, like those just mentioned, the plan very naturally presents itself to lead the water through a battery of radiators, in which case the water can be utilised with advantage. If the radiators are placed at the floor near an air-opening, and are built around, so that the radiation of heat inwards towards the room can be prevented, a simple and cheap ventilation can be obtained in the summer-time. During the winter, again, the air in the room is warmed by the radiators, and heating is thus obtained gratis.

In employing the cooling water for heating or ventilation purposes, open expansion tanks must, of course, be arranged.

### Piping, Silencers, etc.

The reliability of a power installation is secured not only by the adoption of first-class engines, but by a detailed plan being drawn up respecting the necessary transport of fuel, the best arrangement of the piping, etc.

**Inlet-Piping.**—On account of the reciprocating motion of the piston, the gas and air pass very irregularly to and from the engine. When, for example, the piston of a 4-stroke engine begins its suction stroke, the speed of the piston is nil; at the middle of the stroke it has reached its maximum, and, after another quarter of a revolution, it has again fallen to nil. During this stroke, therefore, the gas-masses have their movement rapidly accelerated, and afterwards equally rapidly retarded. During the three following strokes, on the other hand, no gas at all streams into the cylinder. It is clear that variations of pressure, with consequent oscillations of the gas, must thereby ensue. An indispensable condition for the good running of the engine is, however, that the gas shall, as far as possible, follow the movements of the piston. As a matter of fact, all mixing valves are constructed in accordance with this assumption. If then, the air and gas come into violent oscillation, the proportions in the charge will be altered during the suction-strokes that follow each other, damaging not only the economy of the engine but also its powers of regulation and its reliability. These oscillations are especially unfavourable when several engines are connected to the same piping. For this reason, an effective damping is tried to be obtained by means of air- and gas-tanks arranged as close as possible to the engine. Further damping may be obtained by means of throttling in the valve openings at the intakes of the engine.

The piping, which should be as short, and with as few bends as possible, can be suitably dimensioned to a gas-speed of 60-80 feet per second, counted with reference to the mean speed of the piston.

With respect to the air-intake, it should be borne in mind that this, like the air-piping, ought to be so arranged that the air sucked in can be kept as cold as possible. The colder the air, the greater the weight of it that can find place in the cylinder, from which a greater power can be obtained than if the air entered warm. The air-piping should, therefore, be kept well apart from the hot exhaust-pipe, while, on the other hand, the gas- and the air-piping can very well be arranged in the same canal. Care should also be taken that the air-inlet is so arranged that the air can be obtained as dry and pure as possible. When fixing the piping, it is important to remove all sand, etc., from the various parts of the pipes before they are put together, as otherwise dirt can get into the engine when it is started, and can there give rise to many unpleasant interruptions in the working.

An account has already been given of the apparatus for the removal of moisture from the gas-piping, and the ventilation of the same, especially as regards suction-gas plants (see Part I., Chapter III. (c)).

**Exhaust-Piping.**—The area of this piping ought to be at least 10-20 per cent. greater than the free area of the exhaust-valve, all in proportion to the length of the piping. In the case of two-stroke engines, especially, a free and unhindered outlet for the gases is of the greatest importance.

That part of the exhaust-piping which is in the engine-room is usually water-cooled in order to prevent unpleasant radiation of heat. In many cases, such as when liquid fuel is employed, the cooling can take place in a very simple manner by the injection of water into the piping. In the case of suction-gas plants, where the waste gases often contain sulphur dioxide, this method cannot be employed, as the piping would then be corroded. It should, however, be observed that the whole amount of the cooling water must not—as in the case of a number of marine engines—be injected into the piping, irrespective of the retention, under all circumstances, of a free outlet for the gases. For it has happened that the cooling water of such engines has formed a kind of dam in the piping, whereby the power has been reduced, and noise and knocks have been occasioned.

In the case of stationary plants, the piping is made of cast-iron. Wrought-iron is also used, but it rusts quicker. Even zinc roofs are soon attacked if the piping has its outlet above it. Careful isolation is, of course, required, in order to prevent fire, when the piping is lead through the roof and walls.

In the event of any unpleasantness from the radiation of heat from the piping, and its not being desirable to use water-cooling, a powerful circulation of air can be used instead. For this purpose the piping is surrounded with a casing through which the air is sucked by means of a fan.

A proposal has been made, in the case of large plants, to make the piping of reinforced concrete, the piping then being made in lengths, and the joints filled with cement. The cooling should be effected by injection of water. However attractive this plan may appear, it is probably doubtful whether concrete would prove to have sufficient power of resistance against the exhaust gases and the acids formed with water-injection.

**The Utilisation of the Heat of the Waste Gases.** As about 25-40 per cent. of the disposable amount of heat in the fuel escapes with the exhaust gases, it is quite natural that attempts should have been made to make use of the latter, as is done with the exhaust gases of steam-engines. For this purpose the gases are conducted through tubes lying under water, or around boilers from which the steam produced, or the heated water obtained, is passed through radiators. In this way it has been found possible to utilise about 3-10 per cent. of the heating value of the fuel; or, in other words, up to 1600.B.T.U. per H.P. per hour can be regained. This method can, thus, be worth adopting when heating is not required early in the morning, but first after the engine has been at work some time. But when a foreign firm announces in its catalogues that, in addition to the 21 per cent. of the energy of the gas that is utilised as engine-power, its engines permit of a further utilisation of as much as 10 per cent.—and that, too, without any expense—so that the total efficiency of the engine amounts to 64 per cent., we must suppose this to be a more than usually obscure expression.

Sometimes the gases are led direct through the radiators—a method which should, however, only be employed in such cases where no great demands are made on the quality of the air. Dust that gathers on the radiators will apparently spread an unpleasant smell.

**Accessories of the Piping.**—In order to diminish the noise caused by the sucking-in of the air, as well as by the exhaust gases, large reservoirs are employed, which bring about an equalisation of the pressure.

A silencer for the air-piping is used, not only to diminish the noise, but also that the air may come to rest before being sucked in, thereby allowing of the separation of impurities. It ought to be arranged close to the engine, and to be at least three times as big as the piston displacement—the larger the better. It is advantageous to compel the gas to alterations of direction inside the reservoir, but in the piping this should be avoided; otherwise great resistance is occasioned.

The engine-bed is often designed to serve as a reservoir (see fig. 80); but, in such a case, the foundation must be well covered, so that it will not be damaged by any explosions that may take place in the piping. Such explosions can easily arise when the engine is first started, and then sand and brick dust may get into the cylinder along with the air. A sufficiently noiseless air-intake can often be got merely by providing the extreme end of the air-piping with a number

of fine slits. The reservoirs are made of wrought iron, or are cast. In the case of large plants large underground culverts are constructed, which are put into connection with the piping.

**Silencer (or Muffler) for the Exhaust-Piping.**—The greatest difficulty as regards noise is, without contradiction, that caused by the exhaust gases. It is worst in the case of two-stroke engines, as in such engines the gases begin their exit suddenly and complete it in a very short time. But, even with four-stroke engines, the noise from the exhaust-piping is very unpleasant, unless special arrangements are made.

When the exhaust-valve is opened, the gases rush out of the cylinder under a pressure of several atmospheres, and so for the first few moments the valve is kept open, the velocity of the gases amounts almost to a thousand feet a second. It is clear that this must occasion much noise. The leading principle of the silencer must be to produce as equable a stream of gas as possible, with the least possible throttling of the gas. From this point of view it is clear that a multi-cylinder engine is better off, as regards silencing, than a one-cylinder one. In order to obtain this result, the first thing to be done is to reduce the pressure of the gas inside the piping until it is as nearly as possible that of the open air, before being allowed to rush out. By this means we also manage to cool the gas by expansion. Care should also be taken that the speed of the gas at the outlet should be little, and as constant as possible.

A plan which was once much in use consisted in throttling the outlet. It will easily be perceived that in this way the rushing out of the gas can be delayed and extended over a longer period, but then the power of the engine is reduced very considerably too. This method cannot be recommended, therefore, and it should on no account be permitted in the case of two-stroke engines, as the scavenging is thereby hindered. In such two-stroke engines where scavenging is carried out by means of the new charge, pre-ignitions can easily take place too. It is of advantage for the silencing to divide the escaping gas into a number of smaller streams— which can easily be done by providing the extreme end of the exhaust-pipe, with a number of long narrow openings in the longitudinal direction of the pipe. Then, as the gas approaches the outlet, a gradually increasing expansion, and a diminution of the speed, is obtained. But still, without connecting a large reservoir to the piping, it is impossible to get any silencing worth speaking of. It is sometimes necessary to reduce the volume of the reservoir—the so-called silencer—to three times the piston displacement; while in other cases it is made as much as twenty times the same volume, for the larger the silencer is, the better is the result. The silencer should be placed as near to the engine as possible, partly because the resistance during the exhaust-stroke becomes less, and also because the silencing obtained is better.

Fig. 66 shows a silencer which is divided into two chambers to

which the gas is allowed to stream out through conical nozzles. Ample means are provided for draining.

Sometimes the silencer is made entirely in one piece, so that it is scarcely possible to think of taking it to pieces again. As, however, lubricating oil and other impurities accompany the gas, cleaning is always necessary now and then, so that such a construction cannot be approved of.

With marine engines, especially, it is sometimes the custom to inject water into the silencer, or into the piping, thereby cooling the piping, and at the same time a better silencing is obtained. In such cases, however, the silencer ought to be provided with automatically acting drain-pipe. A simple way is to have two pipes leading from the silencer, one for carrying off the water and one for carrying off the gas.

The plan is sometimes used, with marine engines, of letting the gas escape under water. By this means good silencing is obtained,

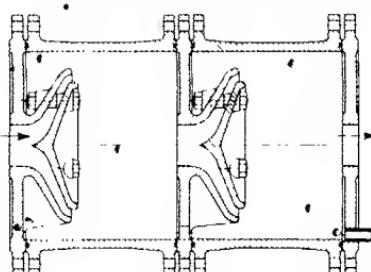


FIG. 66.  
(A.-B. Armaturfabriken Carl Holmberg.)

with the vibrations of the vessel itself, the unpleasantness will, of course, be accentuated.

For silencing purposes in the case of large plants, a brick or concrete shaft is used, which is sometimes filled with a heap of stone blocks. The plan is also employed of letting the gas stream into large vertical cylinders, which open at the bottom into water. The gas then periodically drives away a part of the water, and this results in the gas leaving the cylinders at a pretty nearly constant speed.

#### Accessories for Illuminating-Gas Plants.

The **Gas-pressure Regulator** has for its object to keep the pressure in the piping nearest the engine constant, so that the alterations in pressure in the street mains shall not act as a hindrance on the engine, nor the engine act on the pressure in the mains. For this purpose reservoirs are used, usually of rubber, which are connected to the gas-piping close to the engine.

and the smell of the gas is also avoided; but the power of the engine is diminished on account of the resistance, especially with two-stroke motors. Somewhat unpleasant vibrations may arise, however, in the case of boats of narrow beam, when the engine-power is large in proportion to the size of the hull. If the shocks occasioned by the gas are coincident

If the pressure is subject to great alterations, it may be advantageous to make use of a gas-regulator, and, in addition, a rubber reservoir between this and the engine. The gas-regulator just mentioned consists chiefly of a float lowered into water, and which, by the action of the gas-pressure, more or less throttles the inlet-pipe by means of a valve. Such an apparatus can thus lower the pressure if this should happen to be too great; but, on the other hand, it cannot increase a low pressure, and if, therefore, the pressure in the mains is itself very low, such an apparatus will sometimes do more harm than good. By more or less loading the float the regulating valve can be adjusted to different pressures.

Great care should be taken not to open the holder, unless the valves on each side of it are closed, or else the poisonous, explosive, illuminating gas will stream out.

The float is sometimes replaced by a diaphragm, against the one side of which the atmospherical pressure is allowed to act freely, and past the other side of which the gas passes.

The **Gas-Meter** should be located in a place protected from frost, preferably in the same room as the engine. It is of advantage for the owner of the engine if the gas is supplied to the meter as cold as possible, for the colder the gas is, the greater is its weight and, consequently, its heating value per volume-unit.

### Lubrication.

Without efficient lubrication the best engine works badly and will soon be worn out. Thus, besides providing for good lubricating arrangements, it is also of equally great importance for the engine to be really well attended to in this respect. In order to diminish as much as possible the need of such attention, automatic lubrication is to be highly recommended.

The chief aim of all lubrication is to prevent an immediate metallic contact of the parts that glide upon each other. By introducing a layer of oil between them, the friction is diminished and the heat is also carried off better. For the lubrication of the bearings the same rules hold good, on the whole, as in the case of other engines. On the other hand, there are some special points as regards the lubrication of the cylinder, as its working-surface stands alternately in communication with the piston and then with the hot gases of combustion, the temperature of which rises to  $2700^{\circ}$  F. and more.

It has been asserted that the cylinder-oil must necessarily have a high flashing-point (see p. 60). It is, however, impossible to obtain a lubricating oil which does not vaporise at the high temperatures to which the walls of the cylinder are exposed. The fact, therefore, that the oil vaporises at  $100^{\circ}$ - $150^{\circ}$  F. higher or lower temperature is, in itself, a matter of little importance; the factors which determine the greater or lesser suitability of a lubricating oil are altogether different.

If we compare two lubricating oils, with flashing-points of 300° and 650° F. respectively, it is evident that a lesser amount of the oil with the higher flashing-point is consumed; but, on the other hand, this part will burn worse. In other oils, more solid products of combustion are formed by it. The 650° F. oil is more viscous, and part of it is coked at the same temperature at which the lighter oil is completely vaporised or burned. In contrast with the steam-engine, where the steam which condenses on the walls of the cylinder acts as a lubricator, the air and the gas which are sucked in are not pure, but are full of dust. These solid particles which cake together with the products of combustion from the lubricating oil act as a polishing substance, and can give rise to most unpleasant disturbances in the working.

It being thus impossible to escape from the combustion of the lubricating oil, we are driven to the conclusion that it is best to use such oils as can be completely vaporised. This condition is fulfilled in general by oils of low viscosity, and with low flashing-point. But it must be noticed, first, that the value of the oil as a lubricator lessens with its lower viscosity and, secondly, that a greater quantity of oil is vaporised, thereby adding to the cost of the lubrication. In addition to this, one can hardly speak of any real combustion of the oil, as this has not the opportunity of mixing sufficiently well with the air. Instead of this, the oil accompanies the exhaust gases, vaporised but, for the greatest part, unburned, and thus gives rise to smoke. A middle way is thus adopted, and lubricating oils are used with a flashing-point which, for larger engines, amounts to 450°-510° F.; but, in the case of smaller ones, only to 300°-370° F. Still, thicker oils are also used with smaller engines when these have got worn.

But, in addition to this, lubricating oils must have certain other qualities. They must be free from acids, as otherwise the surfaces are attacked, while other constituents, such as sulphur, also occasion damage. It is thought that it has also been observed that, when the oil contains corrosive constituents, they attack the piston and the cylinder more when powerful cooling has been used. If the lubricating oil which drops from the cylinder is of a brown and dirty colour, it is a sign that something is amiss. If, on the other hand, the lubrication is good, and the cooling is carried out as it should be, the piston and the cylinder remain clean and shining, under the supposition, of course, that the combustion of the engine is itself good. Nothing but the so-called mineral oils should ever be used for the lubrication of the cylinder. It should, perhaps, be mentioned, that the chemical composition of the oils is "no absolutely reliable" guarantee of their value as lubricators, as an unimportant alteration in the atomic grouping of the carbon and the hydrogen may often have a surprising influence on the nature of the oil.

As regards the use of *graphite*, the most contradictory results have been obtained. In some quarters the very best results have been

observed, while elsewhere its use is condemned.' It should, above all, be clearly understood that graphite can never entirely supersede lubricating oil. The surfaces of the cylinder and piston always possess a number of small hollows, with whatever exactness the casting and grinding may have been carried out. If graphite be introduced into the cylinder, it fills up all the hollows and contributes to form perfectly smooth rubbing surfaces—for the oil to lubricate. In some quarters it has been observed that graphite, as a lubricant, produces increased wear, while the experience of others is quite the opposite. This difference in opinion can probably be explained by the fact that bad graphite has been employed containing particles of earth and clay. In the event of graphite being used, care should be taken to procure it perfectly pure. If this is not possible, graphite lubrication should not be employed.

It has also been asserted that graphite is of no use for combustion engines, as it would stick fast to the electric igniters, thereby causing irregularities in the ignition. The fact is that graphite lubrication has been used on a large scale in the air-cooled automobile motors used in America, and with good results, including a considerably diminished consumption of lubricating oil. In the case of steam-engine plants, graphite is known to have reduced the consumption of lubricating oil to one-third, and, in the case of marine engines, graphite alone is sometimes used in order to escape from oil-deposits in the condenser and boilers. It should be remarked, however, that with steam-engines (and *saturated* steam) the steam condensed on the walls of the cylinder acts in some degree as a lubricator. For this reason all kinds of cylinder-lubrications have nowadays been done away with in the greater number of large steamers where superheated steam is not employed. It should also be remembered that graphite, unlike oil, does not vapourise, and that, when once it has stuck fast in the depressions in the surfaces, it is not so easy to remove. One advantage with graphite lubrication is, therefore, that it need not take place continuously. A mixture of graphite and grease has proved useful as a lubricator for gearing, etc.

For the bearings, common, good, acid-free oils can, of course, be used.

In the case of a number of vertical, completely covered-in four-stroke engines, the crank-case is filled with oil so much that the lower part of the connecting rod dips into the oil at every revolution, the oil being then splashed over the walls of the cylinder and the enclosed movable parts. By means of cast-iron grooves the oil is led in a suitable manner to the crank-bearings. In steam-engines of this construction a mixture of oil and water is used; but this should never be done with combustion engines, for in such a case the water mixes with sulphur and other corroding compounds from the gases which leak out. The acid thus formed attacks the rubbing surfaces slowly but surely, and blackens the crank-shaft. This method of lubrication is very simple and effective, but suffers from the inconvenience that

the lubrication of the piston-pin is somewhat unreliable. In addition, oil may easily get up into the cylinder if the engine has been running for a long while at no load, as then the mean pressure in the cylinder is considerably lower. Then, at full load, the temperature in the cylinder suddenly rises, so that the large amount of lubricating oil there is burned, giving rise to smoke and smell. This can be observed in motor-cars which stand still a moment while the motor is kept running. As soon as they start again they give off a cloud of suffocating smoke.

In those cases where the lubricating oil is supplied to the bearings under pressure, the oil-pipe may open on to the pressure surface. In other cases, on the other hand, the oil ought to be led to that part where the surface-pressure is least. The oil is then carried by the journal also to those parts of the bearing which are under high pressure. If, on the other hand, the oil-pipe opens at a place where the pressure is high, it might happen that the oil will not be able to make its way out. Many a case of overheating of the bearings is the result of neglecting this simple rule.

As regards the **consumption of lubricating oil**, no general rule can be given, as it depends on a number of unforeseen factors, arising, in the first place, from the construction and the attendance. As a guide to estimating the consumption, the following figures may be given, obtained from easily running and carefully attended-to engines:—

*Large gas-engines* (about 1000 H.P.), on the four-stroke system, consume about 0.7-1.3 grammes oil.

*Medium-sized gas-engines*, four-stroke system, consume about 2-3 grammes oil.

*Medium-sized Swedish Diesel motors*<sup>1</sup> consume about 0.13 grammes cylinder-oil and about 1.7 grammes bearing-oil.

*Small, high-speed petrol, and paraffin motors* require, as a rule, a much larger amount of lubricating oil, 15-25 grammes and more, all per B.H.P. per hour.

When, in two-stroke engines with compression in the crank-chamber, the compressed scavenging air rushes into the cylinder, it carries the lubricating oil with it, a part of which is burned, while a part gives rise to smoke. That part of the lubricating oil which is burned acts as fuel, and thus is of use. But, on the other hand, it should be remembered that lubricating oil is many times more expensive than the paraffin which is used as fuel. In publishing the results of fuel-consumption tests it would, therefore, be very desirable for an account to be also given of the consumption of lubricating oil. Otherwise, the results given of such tests, especially with two-stroke engines with compression in the crank-chamber, are only of little value. With a two-stroke motor of this kind, well-constructed and run on paraffin, the writer has, in one case, found a consumption of lubricating oil of 23 grammes per H.P. per hour. At the then price

<sup>1</sup> Results of eight months' running at the Norrköping Electricity Works.

of oil, the expense for lubrication amounted to 30 per cent. of the cost of fuel-oil.

### Foundations.

It is best, when possible, to sink the foundation down to solid rock; but if this cannot be done, it must be prepared in accordance with the ordinary methods of laying foundations. The foundation, consisting of good brick or concrete, is laid with a large surface at the bottom, decreasing towards the top. The depth should always be lower than that reached by frost. In order to prevent the propagation of vibrations and noise, the foundation should, if possible, be isolated from other foundation and building-walls. It is often suitable to put cork, felt, or the like, in the intermediate space; in other cases an actual air-space can be arranged. As regards the form of the foundation, care should be paid to place the centre of gravity as low as possible. In the case of two engines connected by belting, it can often be suitable to arrange them both on a common foundation, as in such a case, the forces arising from the belting and acting on each engine are neutralised in the foundation itself. This can be done, for example, when an engine drives a dynamo by means of belting, and when the latter and the engine are not at too great a distance from each other.

In erecting engines on the floor of factory buildings, an examination must, of course, first be made to see if the beams are likely to withstand the future vibrations and loading. A substructure of planks, with isolating material between, does good service as a rule, but care must in any case, be taken that the foundation-bolts do not actually transmit the noise and vibrations instead.

### III. DIFFERENT SYSTEMS OF GOVERNING.

Only in very special cases can use be found for an engine that works reliably only with constant, or almost constant, load, or that runs with great variations in speed. As a rule, just as great demands in respect to power of governing are made on combustion engines as on other prime movers. The only difference is that the difficulties in carrying out these requirements are, in the case of the former, so much greater. In order to indicate a few of the difficulties caused by the method of working, the following may be mentioned:—

The working medium of the gas-engine (the mixture of gas and air) is supplied to the engine from the producer, working under different conditions of gasification, at atmospheric pressure only when small variations in pressure have great influence on the weight-amounts of air and gas sucked in. Within the valves both the gas and the air have to pass through openings of various sizes, in which the speed is dependent, not only on the vacuum in the cylinder, but also of the pressure in the inlet-pipings. In these latter, again, the resistances are not constant—in addition to the fact that different

heights of the barometer and temperatures of the air, and, above all, the oscillations of the gas within the pipings, influence the proportions of the charges. Finally, when the gas and the air come into the

cylinder, they are mixed with the neutral gases remaining there after the previous exhaust stroke. These gases can vary very greatly, both in amount and temperature. It is, therefore, not astonishing that, after the charge has been ignited, the combustion shows variations in character, in agreement with the varying conditions, even if the load has been the same.

Figs. 67 and 68 show some indicator cards of gas-engines taken by the author. Fig. 67 consists of 50 cards taken immediately in succession from an older *Otto* illuminating-gas engine. The ignition takes place by means of exterior flame, which, with the help of a valve sliding to and fro, at the beginning of the expansion stroke is put into connection with the charge (p. 121). The engine in question is still used, and drives an electric generator. The compression is 43 lbs. It is clearly seen with what great variations in the position of the piston the ignition takes place; this, however, may partly be the result of the cards being taken at half load, and also of the construction of the engine being such that the gas and the air are only badly mixed together before entering.

Fig. 68 shows 100 cards taken immediately after each other on a modern 150-H.P. gas-engine directly connected to an electric generator. The engine is run on producer-gas under constant load. The fact that, in spite of such a very great variation in the combustion, a capacity of regulation has, however, been reached which renders possible the employment of gas-engines in electric power plants, shows how perfect the regulation of a modern gas-engine is.

In the case of the steam-engine, the governing always takes place by the work which the steam delivers to the piston at each working stroke being altered with the load. In the case of combustion engines, on the other hand, there is used, in addition to this method, the one of omitting entire working periods. The chief systems of governing are:—



FIG. 67.



FIG. 68.

### Governing by Retarding the Ignition.

The card shown in fig. 69 illustrates this method, which, nowadays, is used only for certain types of small engines provided with electric ignition. In normal working the ignition takes place a little before the dead centre; but, in the case of light load, it is retarded to the beginning of the working stroke. As is seen, the arc of the card is, it is true, certainly less than the normal one, but this has been attained by a less effective utilisation of the fuel introduced into the cylinder. If, therefore, an engine with such governing is run at half load, it will use about as much fuel as with full load. The engine hereby becomes very uneconomical, besides the fact that its running is more uneven, and that, with a low number of revolutions, the crank-shaft can, under certain circumstances, become heavier loaded. It is true that the maximum pressure in the cylinder is less, but, at certain positions of the piston the pressures may be larger than the corresponding ones at normal running. At 40°-50° crank-angle from the upper dead centre, the twisting moment attains its greatest value, a fact which is of importance in judging the stress in certain parts of the crank-shaft. For shorter governing periods this system does very well, however, but should not be used in other cases. If we go to extremes, we obtain a method of governing which consists in letting the engine at light loads suck in its charge as usual, but to interrupt the ignition for a shorter or longer period.

**Hit-or-Miss Governing.** The chief aim of this governing is always to let the engine work under the most favourable conditions, not only as regards the composition of the charge, but also as regards its compression and the moment for ignition. As a matter of fact, this aim is fulfilled only in a moderate degree, even in the case of modern designs.

The governing consists in varying the frequency of the working impulses to accommodate changes in the load. The "miss" strokes are attained in different ways. As a rule, the governor with light loads shuts off the admission of fuel to the cylinder, air being admitted as usual, however, so that, during the succeeding strokes, the engine is kept in motion merely by the energy of the fly-wheel. Then, after an unimportant reduction in the speed, the governor will again allow of fuel being supplied to the cylinder. In better kinds of gas-engines we find this method of governing very seldom used nowadays, unless with small powers; while, on the other hand, it is still extensively used in connection with small oil-engines. One very great reason why this system has come so much into use is that the governor-gear, as a whole, becomes very simple and cheap. The



fuel-oil is introduced into the cylinder by means of the plunger of the oil-pump engaging with a pick-blade, which latter is actuated by a cam or eccentric. At light loads the governor has nothing else to do than to pull the said pick-blade aside so that the plunger is not acted on. The power of the governor can, therefore, be exceedingly small, which, in its turn, permits of the employment of the simplest constructions (see figs. 110 and 131).

As we have said, with this method of governing fuel and air are always introduced into the cylinder in the proper proportions; but, still, the great economy of fuel attained is not attained. The omission of the ignition during one or several successive revolutions causes a cooling of the cylinder, thereby pretty often occasioning loss of fuel and the dirtying of the cylinder by after-combustion, as well as irregularities in the ignition.

In order to diminish these inconveniences, attempts have been made to prevent the drawing-in of cold air into the cylinder during the "miss" strokes. In the case of four-stroke engines, this can be done by keeping the exhaust-valve open, and the inlet-valve shut, during the suction stroke. But then, the exhaust-valves will soon become dirty, however. If automatic inlet-valves are used, these must be kept pressed against their seats by means of springs. Another method is to keep the inlet valve closed during the suction stroke, while, on the other hand, the movement of the exhaust-valve is not at all altered. Apparently, this will cause a high vacuum in the cylinder. In the case of two-stroke engines the same result can be attained by closing the air-intake to the cylinder. This regulation can also be carried out very simply, but is, nowadays, being replaced by better systems. All these constructions unite in themselves most of the inconveniences of the hit-or-miss governing proper, without possessing its advantage, simplicity. For purposes where great demands are made on speed regulation, such as, for example, in running dynamos, textile machinery, etc., hit-or-miss regulated engines are not very suitable, as the fly-wheel weight which then becomes necessary is very considerable.

**Constant-Quantity Governing.** In this system of governing, only the amount of fuel (gas or oil) is altered with different loads, while,

on the other hand, the compression is kept constant (fig. 70). In the case of gas-engines there is, thus, drawn in a varying amount of gas; but, the total amount of air and gas sucked in remaining constant, the percentage-proportion of air is increased with lower load. At the end of

the suction stroke the same pressure always prevails in the cylinder, and the final compression-pressure can, therefore, not undergo any alteration. Just the fact that the compression-pressure is not

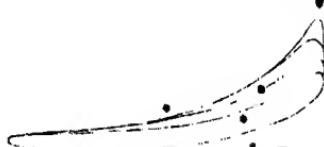


FIG. 70

diminished with lower load, confers important advantages in several respects, and is the strong side of this method of governing.

For, if the compression sinks below a certain degree, then, during the latter part of the compression stroke, there arise variations in the direction of pressure in the pins and bearings, which may become dangerous for the engine. Especially in engines with high piston-speed and heavy reciprocating parts, the designer often needs all that he can get in the way of compression, in order to prevent such impacts. If, then, the compression should be diminished with light load but at constant speed, it will sometimes be difficult or impossible to prevent such variations in pressure. There is often a surplus of compression, however, and then this point of view disappears.

In contrast with the hit-or-miss governing, this, as well as the following systems of governing, makes it possible to keep the variations of speed within very restricted limits, without the use of heavy fly-wheels. Another advantage is that the construction is a very simple one, as, very often, the governor needs only to act on relatively small and light members. In the case of gas-engines, either the hit of the gas-valve is altered, the gas then being allowed to stream into the cylinder during the whole of the suction stroke, or else it is the time during which this valve is kept open that is altered. In the case of oil-engines, the governor acts on the fuel-pump in such a way that either the stroke of the latter is altered (fig. 147), or else its suction valve is kept open during a longer or shorter part of the pressure stroke (fig. 148). A part of the oil which was sucked in will then run back again.

In thermal respects a high compression is of the greatest importance for the economy of the engine, and it is also advantageous to employ weak charges. Thus this method of governing is in perfect accord with these demands. But it should be carefully observed that this holds good only under normal conditions. In the case of very light loads the gas becomes too diluted for the combustion to take place with any great degree of rapidity. It is true that this inconvenience is partly counterbalanced by the high pressure that prevails, and by means of which the ignitibility of the charge is favourably influenced. But the dilution of the gas acts the stronger, however, and so, in reality, the consumption of fuel per H.P. rises considerably, in spite of the constant compression.

By varying the moment for the introduction of the fuel in such a way that at the beginning of the suction stroke only air is sucked in, and afterwards gas and air together, endeavours have been made to obtain a stronger charge around the igniter. One can then, at least, be sure that ignition really takes place; but in the other parts of the cylinder, at a greater distance from the igniter, the gas thereby becomes still more diluted and combustion rendered still more difficult. The varying oscillations of the gas- and air-masses also contribute to the creation of varying indicator cards, and an after-combustion is brought about which sometimes extends throughout

the whole of the expansion stroke. What has been said above has respect, for the most part, to gas-engines, other conditions prevailing in the case of oil-engines.

**Constant-Quality Governing.** With this governing the proportion between the gas and the air remains constant under all loads. But, on the other hand, the inlet is throttled during the suction stroke, so that a smaller amount of gas mixture enters with decreasing load. The consequence of this is that the compression is then diminished (fig. 71).

In contrast with the preceding methods, this governing guarantees, under all conditions, a more reliable ignition of the gas, and, as a matter of fact, the combustion is really better. In addition to this, there is also a greater capability of regulation at light loads. But, on account of a smaller amount of gas mixture being sucked in at light loads, the percentage of neutral gases remaining after the exhaust stroke is increased. On this account, and also because the

compression is diminished, the necessary amount of fuel per H.P. rises at decreasing loads.

As a matter of fact, however, the constant-quantity and the constant-quality governings are pretty equal from a thermal and, in most cases, from a working point of view, too. If a choice is to be made, it would

be the latter, except possibly in the case of some very large engines.

The design with the constant-quality governing becomes very simple. An ordinary butterfly-valve in the intake for the gas mixture is all that is required (see fig. 79), or else the mixture is throttled more or less in the mixing-valve which is controlled by the governor. Fig. 78 shows how the governor may be made to close the mixing-valve at an earlier or later part of the suction stroke, according to the load (see also p. 171).

In whatever way the governing is carried out, however, there arises, at light loads, during a longer or a shorter part of the suction-stroke, a powerful vacuum in the cylinder which increases the pump-work. The valve-springs must thus be made so powerful that they are able to keep the valves pressed down against their seats even at lowest load, when the pressure often sinks to 0.75 atm. vacuum. In large engines, therefore, the springs are given considerable dimensions, and the forces acting on the valve-gear reach considerable amounts.

**Combination-Governing Systems.**—As is seen, the two last-named governing systems offer certain advantages, but they have inconveniences too, which stand in the most intimate connection with the amount of the compression and the composition of the charge. It is, therefore, quite natural that attempts have been made to combine

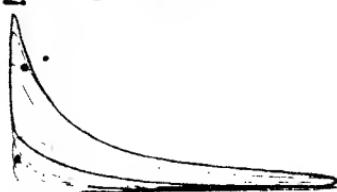


FIG. 71

the two systems. *Mees'* governing is an example of this. At normal load the engine sucks in a comparatively weak but easily combustible mixture which is compressed to high pressure. At heaviest load, on the other hand, a very rich charge is sucked in, which is compressed to a pressure reaching or a little above, that at normal load. Finally, at light load the engine sucks in a smaller amount of charge of similar or almost similar composition as that with normal load. This is afterwards compressed more or less, but, in any case, higher than what it is in an engine working with ordinary constant-quality governing. As is seen, this method of working very much resembles that of the steam-engine, in so far as the engine works most economically at normal load, while the economy of fuel sinks both with increasing and decreasing load.

Another combination-governing system is *G. Eriksson's* of Södertälje, Sweden, which is used in automobile motors. The gas mixture coming from the carburettor has here always the same composition. The charge is throttled at light load, but, in order to be still able to work with constant compression, the engine is provided with an extra automatic inlet-valve which, at light load when higher vacuum arises in the cylinder, opens and admits pure air alone. By suitably arranging valves and sparking plug in respect to each other, a good mixture can in this manner be obtained around the plug, in spite of the constant compression. Tests show relatively little increase in the consumption of fuel at light loads: 6.5 per cent. at three-quarters load, and 23 per cent. at half load.

A correct adjustment of the moment for ignition is of great importance for obtaining good economy of fuel, so that the ignition of the gas is begun at an earlier crank-angle the weaker the charge, *i.e.* the smaller the load. For this reason the governor is sometimes arranged so as automatically to bring about this adjustment.

An alteration of the moment for ignition also provides an excellent means for an accurate adjustment of the speed of the engine, and use is sometimes made of this fact in the synchronising of dynamos driven by gas-engines.

#### IV. DIFFERENT TYPES OF ENGINES.

##### • Smaller Engines.

###### • Gasmotorenfabrik Deutz.

Fig. 37 on p. 110 shows a horizontal engine for illuminating or producer-gas. In order to be able to alter the size of the compression-space in some simple way, a loose plate is put in between the piston-pin bearing and the connecting rod.

Constant-quality governing is used, and this takes place by the simple process of altering the lift of the inlet-valve and thereby altering the port-areas of the slide-valve and the gas-valve. Should the pressure in the inlet-pipings for gas and air not remain constant,

this can be adjusted by hand by means of valves at the intakes. The reader is referred to the description on p. 112.

Fig. 72 shows a section through the cylinder-head of an engine of a somewhat different design. A jam secured to the lay-shaft **a** actuates a push-rod **b** provided with a roller. The lower end of the push-rod is compelled by a short lever **c** to move in an arc. The upper end of the push-rod, on the other hand, stands in connection with the stem **d** of the inlet-valve by means of a horizontal link **d**, arc-shaped on its upper side. The lever **h**, being under control of the

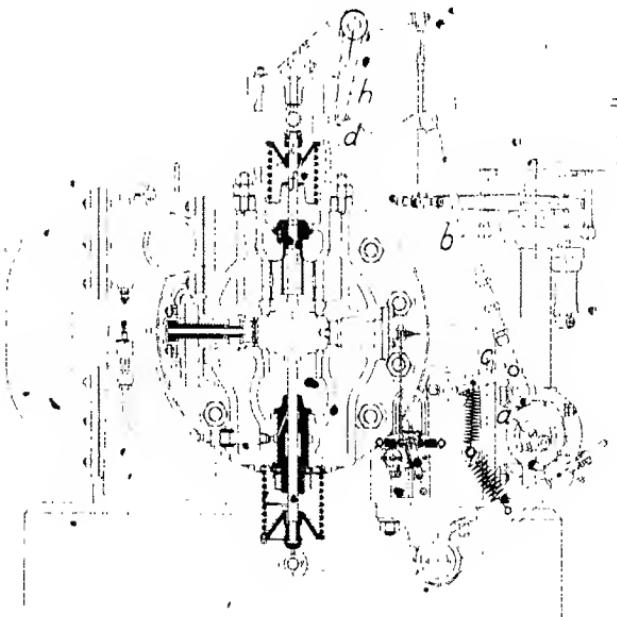


FIG. 72.

governor and acting as a support for the link **d**, will thus be able to move along the same. Consequently, the fulcrum of the horizontal lever, and thus the lift of the valve, will be dependent on the position that the governor has for the moment. By the valve-gear be so adjusted that, when the valve rests against its seat, a little clearance exists between the governor-lever **h** and the link **d**, then, on changing the position of the former lever **h**, there will be no reaction on the governor proper. On the other hand, it is impossible to avoid such a reaction arising every time the valve is opened; and, while the latter is in motion, the governor cannot act unless it is made extra large and powerful. If, therefore, there is a change in the

load during the beginning of the suction stroke, the governor sleeve will not be free to move, until the crank has passed through  $180^{\circ}$ . A great advantage of the construction in question is, however, that the governor is made quite independent of the tar and other impurities deposited on the gas- and the air-valves. This point of view may be neglected when illuminating gas is used, this being perfectly clean.

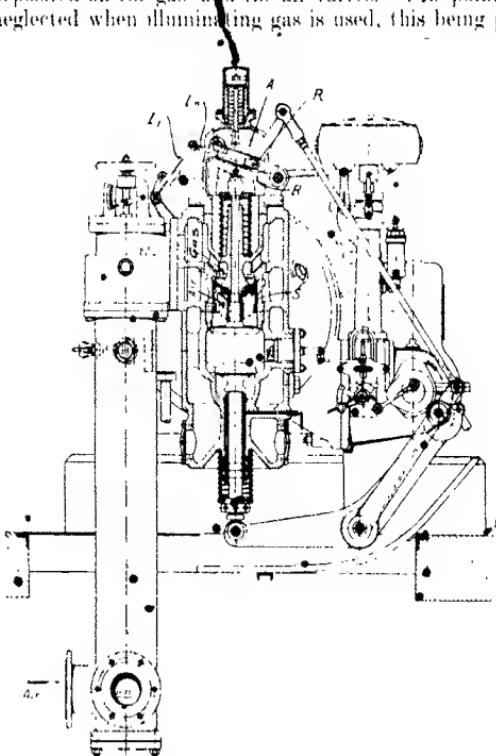


FIG. 73.

The exhaust-valve is operated in the ordinary way by means of a cam and a rocker. The valve, visible to the left in the middle, admits compressed air on starting. Just opposite is placed the igniter.

**Maschinenfabrik Augsburg-Nuernberg.**

Fig. 73 shows a section through the valve-chamber. The aim set in designing the valve-gear of this engine was that it should be possible to use a weaker charge with light load, and a stronger one with heavy load. This end was attained in a simple manner by

making the air slide-valve **S** keep the air-ports a little open, even when the gas-valve is closed. The mixing-valve works—to borrow an expression from steam-engine technicals—with a lead for the air, so to say. Otherwise the regulation takes place by the governor displacing, by means of the links **L<sub>1</sub>** and **L<sub>2</sub>**, a roller **R** between the two levers **A** and **B** which stand in connection **B** with the valve-stem, and **A** with the push-rod operated from the cam-shaft. As may be seen by the illustration a small displacement of this roller brings about a great change in the lift of the inlet- and the air-valves, as the two levers between which it moves are pivoted on opposite sides of the said roller. The governing is thus essentially worked on the

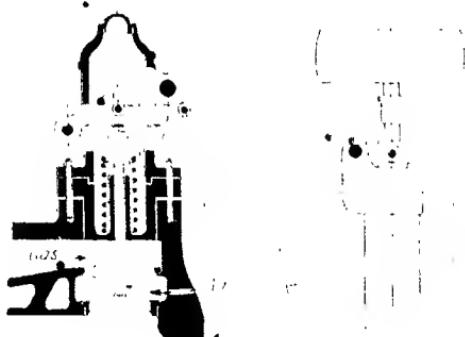


FIG. 74.

constant-quality principle, although with light load the percentage proportion of gas is somewhat diminished. With heavy loads, on the other hand, the little lead of the air-valve loses all practical importance for the composition of the charge drawn in.

#### Gasmotorfabrik Coeln-Ehrenfeld.

Fig. 74 shows the governing employed by this firm. It differs from the preceding one chiefly by the fact that, with light load, only the main inlet to the cylinder and the gas-inlet are throttled. The air-supply, on the other hand, is not acted on by the governor, but can, instead, be adjusted by hand by means of a regulation valve in the air-piping. Thus, the governing consists of something between a constant-quality and a constant-quantity one.

## Crossley Bros., Ltd.

The idea aimed at by the construction shown in fig. 75 has been to endeavour to procure a governing which will make the least possible demands on the governor. During the suction stroke, the valve **a** is opened in the usual way, and it endeavours, by means of the spring **b** to carry with it the gas valve **c**. Air enters through the pipe **d**, and gas through **f**, in which there are placed valves which can be adjusted by hand. The movement of the valve **c** is determined, however, by two factors—viz., by the force from the spring **b** which tries to carry the valve downwards, and also by the vacuum which acts on the

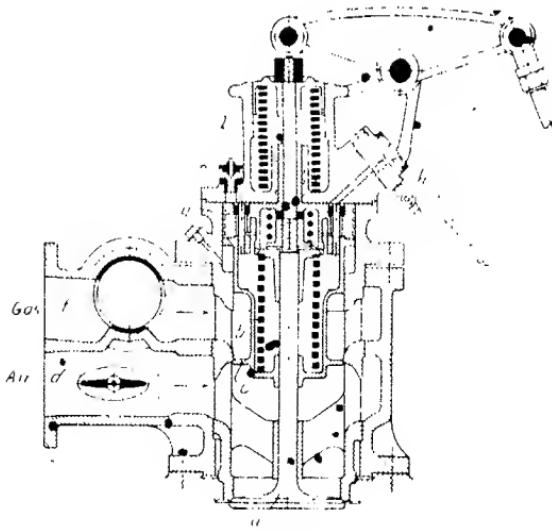


FIG. 75.

upper side of the piston **g**, and tends to keep the valve in its place. The amount of the vacuum is regulated by the little pilot-valve **h**, controlled by the governor, and the frictional resistance of which can be made very small. The inlet-valve **a** is closed by the spring **b**, and the air which has come in above the piston **g** is then blown out through the release valve **m**. As may be seen, the governing is worked on the constant-quantity principle. With well-cleaned gas this governing principle will evidently allow of an extra close speed-regulation.

Fig. 76 shows a section of a 200-H.P. engine provided with this governing. The exhaust-valve is water-cooled. And, finally, fig. 77 is an exterior view of the same engine, which shows very clearly the governor connections. Double magneto apparatus and igniters are arranged in this engine.

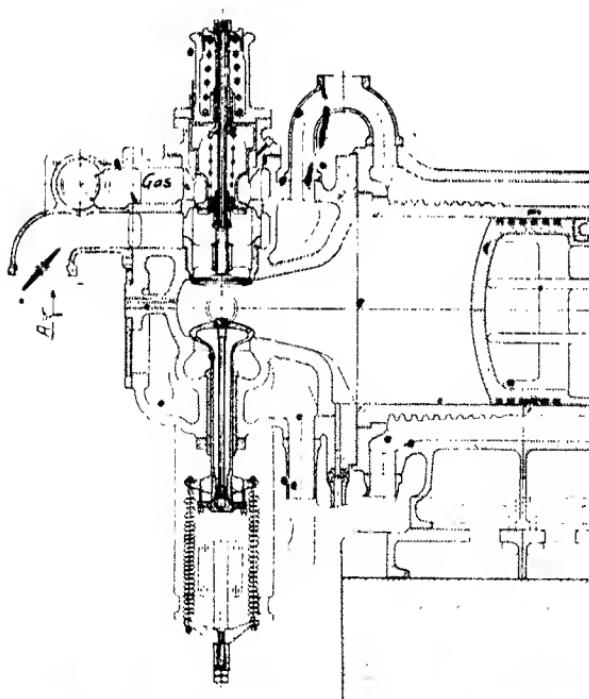


FIG. 76.

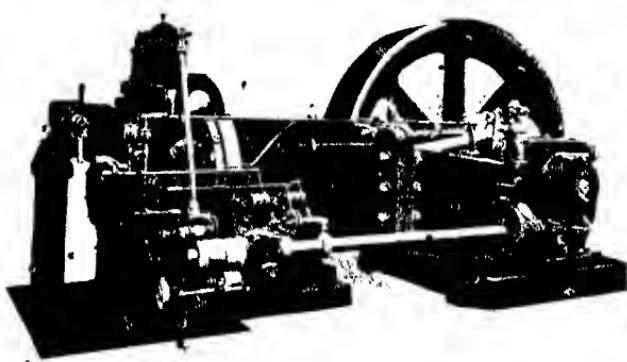


FIG. 77.

## Nydqvist &amp; Holm.

Fig. 78 shows a section through the valve-cage. The gas and the air enter through the pipe shown to the left, which is provided with two concentric canals. Both the air- and the gas-inlet can be throttled by valves adjustable by hand. At the bottom is seen the exhaust-valve, which, in the usual way, by means of a rocker, is actuated

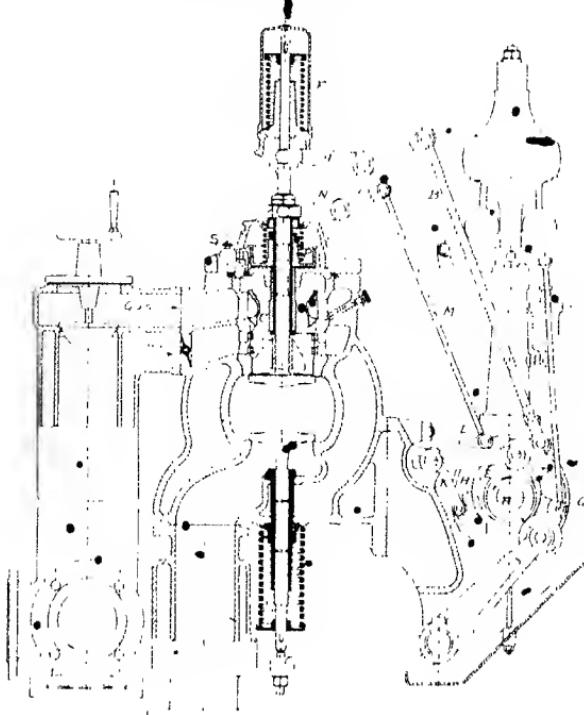


FIG. 78

from a cam rigidly attached to the cam-shaft **H**. The inlet-valve is, as usual, guided in a valve-cage inserted in the cylinder, the valve being pressed upwards by the spring **F**. During the suction stroke, the valve is opened by the lever **A**, which, by means of the rod **B**, is moved backwards and forwards by a cam on the cam-shaft. Around the stem of the inlet-valve there is displaceably arranged a combined air slide-valve and gas-valve **C**, the so-called regulating valve. On the cam-shaft there is keyed—on an eccentric **E**, the ring of which is connected with the governor by means of a projecting arm and pin

**G.** On the opposite side the same ring is provided with a shoulder **H**. It is clear that during the working the eccentric ring will be given an oscillating movement, whereby, during the suction stroke, the shoulder **H** presses the lever **K** away from the cam-shaft. To this lever is rigidly attached another lever **L**, which thus will move downwards at the same time. By means of the rod **M** this acts on the rocker **N**, which thus, during the suction stroke, hits the regulating valve upwards. This latter, however, as is seen, rests against a dashpot **P**, which is acted on by a spring, and which is thereby simultaneously carried upwards. Then, when the lever **K** is released by the shoulder **H**, the regulating valve is carried quickly downwards by the spring-loaded dashpot, which, near its end position, is arrested by the arm under the same. In this manner the valve is gently closed. The air buffer can be adjusted by means of the release cock **S**. Thus, as the eccentric ring, with the shoulder **H**, is controlled by the governor, it is clear that a displacement of the pin **G** will bring about an earlier or a later closing of the regulating valve. With light load the gas- and air-supply is shut off before the close of the suction stroke; but, during the time the valve is kept open, air and gas are sucked in in pretty nearly constant proportion, independent of the load. Constant-quality governing is thus employed.

#### Gebruder Koerting.

Fig. 79 shows diagrammatically a vertical section, and fig. 80 a longitudinal section of a 200-H.P. twin gas-engine. Air is supplied to the engine through the large pipe **a** shown in fig. 79, and gas through the smaller one **b**, which is situated inside the former pipe. The air- and gas-supply is regulated by an automatic valve **v** provided with a dashpot **c**. After having passed the openings of the said valve, the air and the gas meet and pass together through a butterfly valve **d** under control of the governor, and go from there through the inlet-valve cage, which is pierced by a large number of small holes, and, finally, past the inlet-valve into the cylinder. The motion of the inlet- and the exhaust-valves is derived in the ordinary way from the cam-shaft. The exhaust-valve is water-cooled (fig. 80). The water is fed in through the hollow valve-stem, fills the hollow valve-body, and, finally, passes out through a tube arranged in the centre of the valve-stem. As the upper end of this tube is situated near the highest point of the valve, reliable cooling is guaranteed, and the formation of air-pockets is prevented. The water is brought in and led out by means of rubber piping. The piston-head is water-cooled too, and the link-motion necessary for this purpose is shown by the figure. In order to make it possible to employ high compression, an oblong cooler-box **K** is placed in the combustion-chamber, and through this the water circulates (see p. 261). The igniter **T** is inserted in the cooler-box immediately under the inlet-valve. To the lower end of the cylinder is connected a blow-out pipe **R**, through which oil and soot can be

blown out. The lower part **P** of the engine-bed serves as a tank for the combustion air, which enters there through the wooden drum **U**.

### Large Engines.

Large gas-engines have had no very long existence, for the industry in question did not become of any importance until the Paris Exhibition in 1900. Of the firms exhibiting on that occasion the *Société Cockerill*, of *Seraing*, Belgium, awakened well-deserved attention by

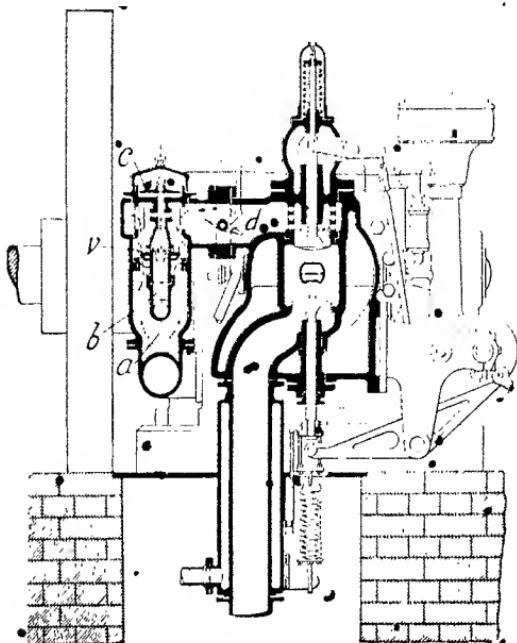


FIG. 79.

its engine of 600 H.P., which was a power unknown up to that time among gas-engines. The firm mentioned continued on the path it had taken, and constructed units steadily increasing in size, which were used at iron and steel-works for the driving of blowing-engines. This great advance was soon noticed in other countries—above all, in Germany and in the United States, where conditions were very favourable for the employment, on a large scale, of engines for blast-furnace gas; and in these two countries a number of firms boldly attacked the many problems which presented hindrances to the employment of these engines. Although the power necessary was to be measured by

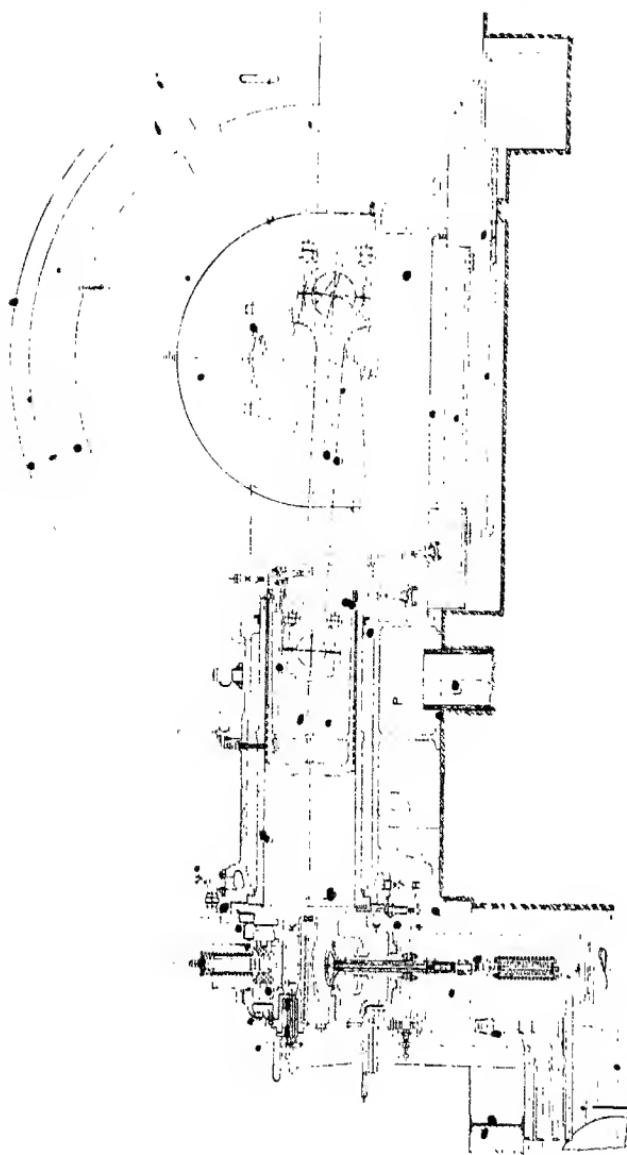


FIG. 80.

thousands of horse-power, an attempt was made at first to proceed in accordance with the principles of design which had been found suitable with smaller engines, and an endeavour was made to produce the necessary units by a combination of a number of smaller engines. It soon proved, however, that this was not feasible. Manufacturers then divided themselves into two camps—the one keeping to the old and well-tried four-stroke system as being superior, while the other party thought that the two-stroke engine would provide a solution of the problems involved.

#### FOUR-STROKE ENGINES.

Although the engines of different firms still present characteristic differences, we may say that nearly all of them show typical features common to all. In the case of powers exceeding about 300 H.P., it is nowadays pretty generally the custom to reject the single-acting for the double-acting type. The simplicity of the former—which is characterised by the absence of cross-heads and stuffing-boxes—becomes, in the case of engines of greater power, of less importance as compared with the essential advantages conferred by a closer approach to the well-tried construction of the steam-engine. As it is nearly always of great importance to be able to reduce the weight of the fly-wheel, two double-acting cylinders are, as a rule, arranged behind each other. By this means, it is true, the engine will consist of a larger number of parts than if the entire power was obtained from a single cylinder; but, on the other hand, important advantages are obtained. One working-stroke is obtained for every half revolution, just as in the case of a double-acting 1-cylinder steam-engine. The piston area, together with all forces, hereby becomes less, and these latter are more equally divided during the power-cycle. The power-transmitting parts are utilised better in this way, the weight of the fly-wheel can be considerably reduced, and the mechanical efficiency is favourable.

In smaller engines without cross-heads, where the side-pressure from the connecting rod must be received by the piston, this latter must be given a pretty considerable length. Unequal expansion of the cylinder and the piston can easily occur, and the risk is thereby run of the piston's sticking, with the consequent injury to the working-surfaces. If these conditions bring about certain difficulties even in middle-sized engines, the difficulties increase in large engines to such a degree that there is a risk of destroying the reliability of the engine. In the case of the double-acting type, on the contrary, there is, of course, a special cross-head (fig. 86), and thus there is no reason to make the piston longer than what is required in order to get room for the necessary number of packing rings. As was mentioned before, the gas is never perfectly pure, but, in spite of the cleaning apparatus, has always a percentage of dust. In order to reduce the inconvenience caused by this to the least possible, the piston is not allowed to act

with its weight against the walls of the cylinder, but it is turned with a diameter considerably less than that of the cylinder, and is kept floated in the cylinder on its piston-rod. The only part of the piston which, during working, comes into contact with the cylinder-wall, are thus the packing rings. No dust or other impurities are squeezed in between the piston and the cylinder, where it would act as a grinding medium, but is swept away to a great extent at least, by the piston-rings.

In order to obtain such a floating of the piston on its rod, the correct principle was adopted that the piston-rod ought to be turned with such a bend that, when it was afterwards loaded with its own weight and with that of the piston, together with the enclosed cooling water, it would take up a perfectly horizontal and straight position.<sup>1</sup> It would be possible, of course, to turn the piston-rod under loading, but in that case it would be necessary to employ rotating cutting tools. As such a method of procedure is pretty troublesome, use is made of a method which, it is true, is not so theoretically correct, but, in practice, gives a sufficiently good result. The greatest deflection of the piston-rod, which, of course, arises in the middle of the piston, is first calculated. After this the parts of the piston-rod lying on either side of the piston are turned, on two different geometrically straight axles which form an angle with each other, and meet at such a height above the middle of the piston as corresponds to the calculated deflection. Then, when the piston-rod is mounted in the cylinder with the piston arranged on it and filled with cooling water, it will take up a position which is very nearly horizontal.

The stuffing-boxes are also spared by this construction, and that to a very great degree, as they need not at all take care of the weight of the piston, as would otherwise be the case after the cylinder has become worn.

As, however, the air-cooling received by the piston in single-acting engines does not here exist, it has been found necessary to arrange for good water-cooling instead. It is self-evident that the piston-rod, too, must be cooled, and for this reason, both pistons and piston-rods are made hollow, so that the cooling-water may circulate through them. Such a device, together with the very high forces to which the piston-rod is exposed, makes it necessary to have it constructed with a great thickness of metal. Certain firms have made use of this fact to escape from the troublesome turning of the piston-rod described above. They turn the piston-rod perfectly straight, as usual, but then make it so thick, and make the clearance between the piston and the cylinder so large, that the piston in any case will not rest against the cylinder-bottom, but will be supported entirely by the cross-heads.

A slight displacement of the packing rings of the stuffing-boxes

<sup>1</sup> This method was formerly proposed by *Collman* for use in steam-engines.

in a radial direction is, of course, a natural consequence of this last-mentioned construction, when the piston moves in the cylinder.

For this reason it is a characteristic feature of all stuffing-boxes in gas-engines that the packing rings are movable radially, whether spring-rings or uncut rings (fig. 81) are used. Fig. 81 shows the Lentz stuffing-box. It consists of a number of uncut packing rings **A**, and intermediate expansion rings **B**. The rings **A** lie as closely as possible around the piston-rod and are movable radially within the rings **B**. The gas that leaks out past the piston-rod is expanded successively in the rings **B**. As is seen, the packing is based on labyrinthic action.

Fig. 82 shows how the cooling water, either from an elevated tank or from a cooling pump, enters into the hollow piston-rod through a stationary pipe. The outer end of the pipe stands in connection with an air-vessel intended to equalise the movement of the water. Another method is shown, by figs. 83 and 84,<sup>1</sup> of introducing cooling water by means of hollow link rods.



FIG. 81.

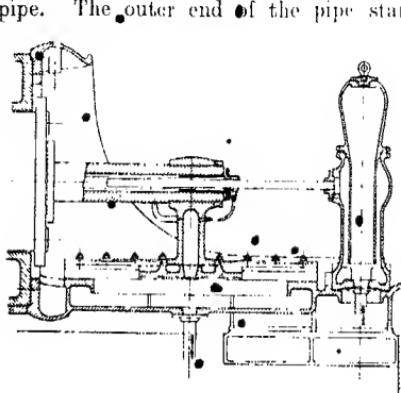


FIG. 82.—

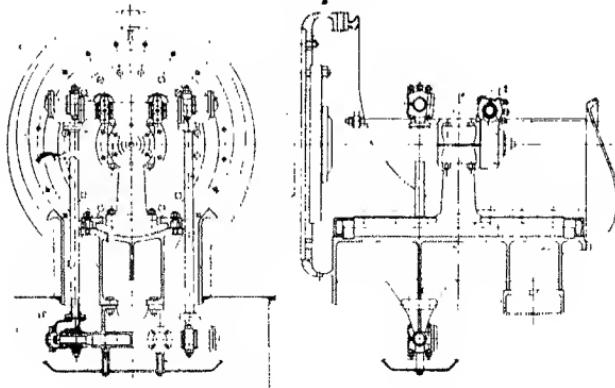
Maschinenfabrik Augsburg-Nuernberg.  
box, and which absorbs the sulphuric acid formed.

In such cases where the gas contains sulphur dioxide, it is of importance for the piston-rod not to be cooled too powerfully, as otherwise it will be attacked by the moisture which is condensed in the stuffing-

box. In such cases where the gas contains sulphur dioxide, it is of importance for the piston-rod not to be cooled too powerfully, as otherwise it will be attacked by the moisture which is condensed in the stuffing-

<sup>1</sup> Figs. 82-84 are from Riedler, *Grossgasmaschinen*.

In the case of large engines, it has proved impossible to use the design of the cylinder-head shown in fig. 37; for its complicated construction, occasioned by the valve-cages, too often caused breakages. The valves, with their cages, have therefore, in modern engines, been removed to the cylinder proper (fig. 83), whereby the head can be given



FIGS. 83 and 84.—Maschinenfabrik Augsburg-Nuernberg

a simple and symmetrical form, as free as possible from cast-strains, and capable of resisting high pressures. The new construction also had the result that the valves and the interior of the cylinder became relatively easily accessible, this being rendered possible especially by drawing out the cylinder-heads.

Respecting the valves, the reader is referred to p. 117.

The valve-gear, with certain types, resembles that employed with smaller engines, but in most cases it is like that of the poppet-valve steam-engines. Thus, in the latter case, the valves will not receive their movement from cams, but from eccentrics which act on the valve-stems (fig. 87) by means of *rolling levers* or *wipers*. The inertia arising from the considerable weight of the valve-gear must be overcome, of course, and this is done more easily if eccentrics are used instead of cams. It might be thought that this expedient is almost self-evident. But

this is not the case, however, for, as the valve is to be kept open for only about one quarter of the time necessary for one revolution, it will only be the shaded part, shown in fig. 85, of the circle area de-

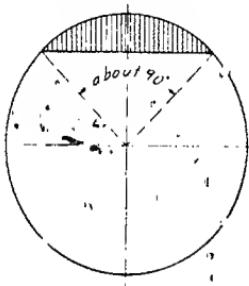


FIG. 85.

scribed by the centre of the eccentric ring that can be employed for valve motion. The result of this is that the object aimed at is dearly bought, as the eccentricities must be made large. This inconvenience is counterbalanced in great measure, however, by combining the rolling levers just mentioned with the eccentric movement. Another advantage is also obtained by this means. The rolling lever can be given such a form that the eccentric will be but little loaded at the beginning of the opening of the exhaust-valve, when a pressure of as much as 30-60 lbs. per square inch prevails in the cylinder. The rolling lever can also have such a shape that the exhaust-valve is opened quickly at the beginning. There are many large gas-engines, however, in which the valve-motion is derived from cams, and which work very satisfactorily. American firms have simplified the valve-gear by actuating both the inlet- and the exhaust-valves by means of one and the same eccentric.

#### Maschinenfabrik Augsburg-Nuernberg.

Figs. 86-89 show this firm's latest construction, which presents important simplifications as compared with the older engines. The new design of the valve-gear, especially, is finely carried out.

The cylinders, which are arranged in tandem, are, together with their distance pieces, connected centrally to each other. The cylinders are entirely supported by the main- and tail-frame, and by the distance pieces, no supports being employed beneath the cylinder-barrels. The main-frame is anchored rigidly, while the distance piece and the tail-frame are provided with surface lugs sliding on their respective sole-plates to allow for expansion. The inner cylinder-barrel and the water-jacket wall are cast in one piece, at a great distance apart, thereby obtaining a very broad end-flange. The stresses which arise on account of the different temperatures of the two cylinders are by this means kept within proper limits.

The piston-rods are turned along two geometrical axles forming an angle with each other as described on p. 176. The stuffing-boxes are provided with a number of cast-iron and Babbitt-metal rings, each one divided in three parts, which are kept pressed against the piston-rod by means of springs. The lubricating oil is supplied under pressure.

In contrast with the older construction, the valves are arranged as far in as possible towards the centre of the cylinder, whereby a less broken-up combustion-chamber is obtained. The valves themselves, not only the inlet- but also the exhaust-valve, unlike the older construction—but in agreement with a number of new German engines—are not water-cooled. Not even the valve-seats are cooled.

The valve-motion is derived from a lay-shaft arranged at the side of the engine, from which the movement is communicated by means of eccentrics and rolling levers to the valves. The exhaust-valve **b** is actuated by positive motion by means of the eccentric **c**,

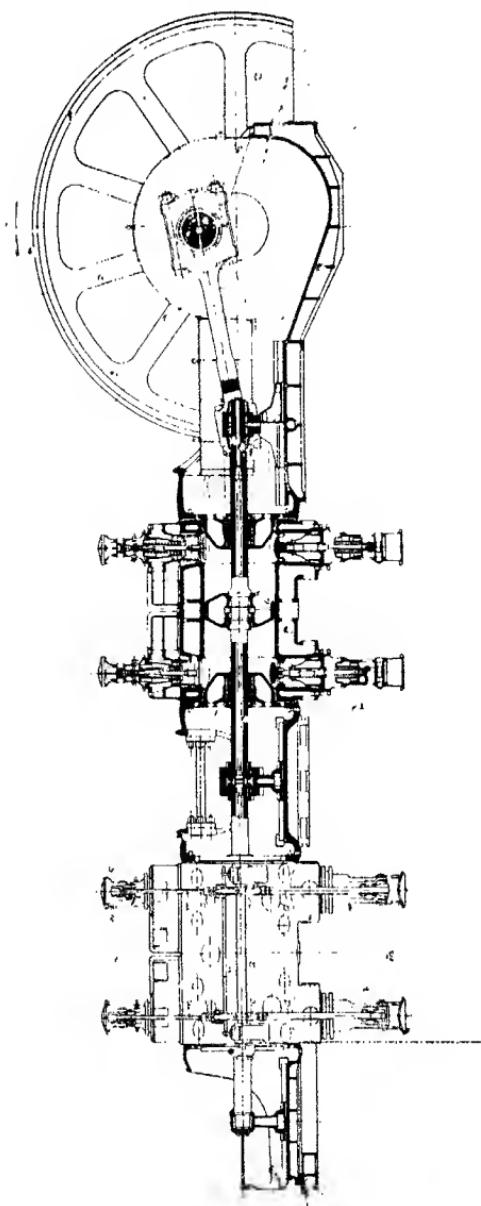


FIG. 86.

the rod **d**, and the rolling levers **f** and **g**, which latter are pivoted around the pins **h** and **i**. In order to prevent dirt getting down to

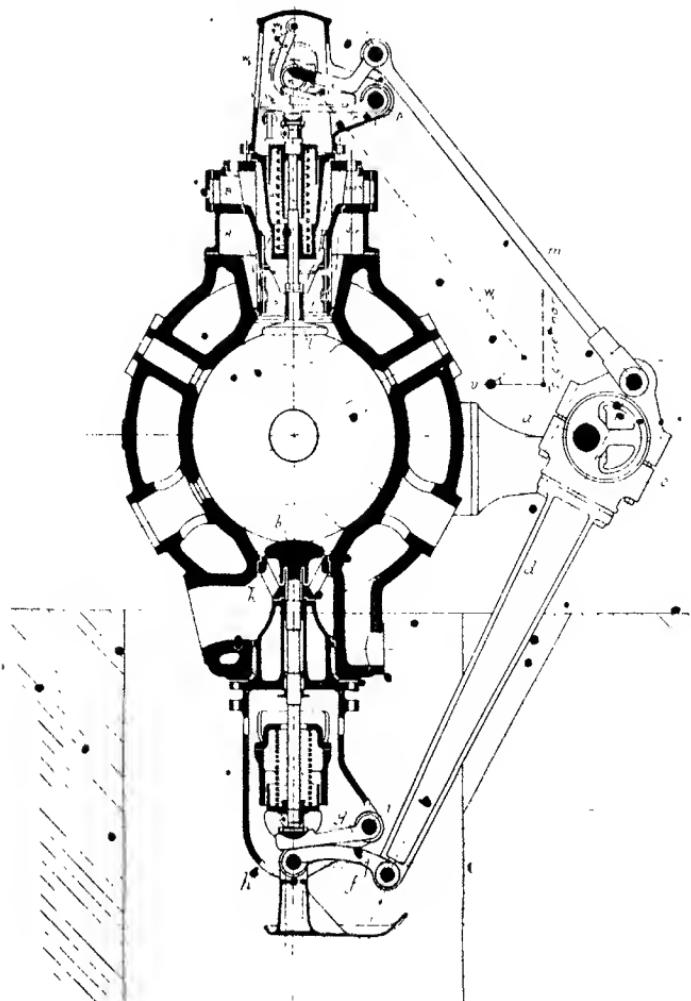


FIG. 87.

the stem, the valve is provided with a long cylindrical guard **k** reaching a long way down and surrounding the valve-guide.

The inlet-valve 1 receives, in agreement with American engines,

its movement from the same eccentric as the exhaust-valve. The rolling lever **r**, fulcrumed around the pin **p**, is actuated by means of the eccentric **c**, by the rod **m** and by the rolling lever **o**, which latter is fulcrumed around the pin **n**. The lever **r** acts directly on the valve **l**. Around the lower part of the valve-stem there is a cylindrical slide-valve **s** rotatably arranged, which accompanies the valve in its movement up and down. Air filters through the space **A**, and

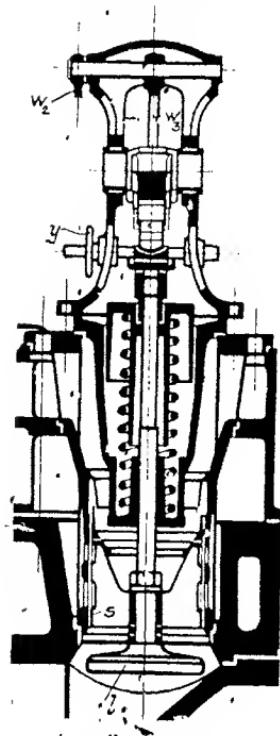


FIG. 88.

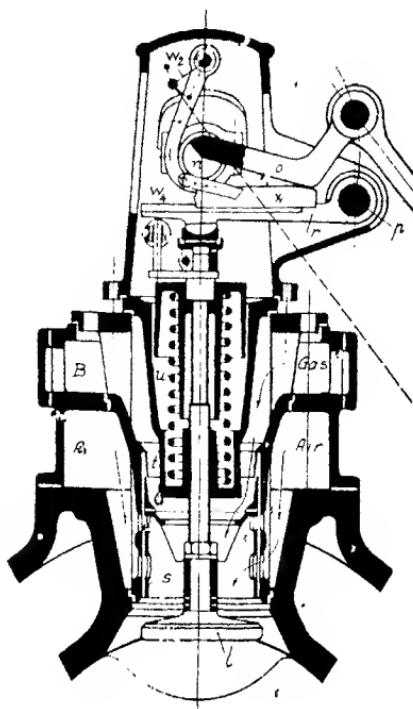


FIG. 89.

gas from **B**. The guard **t** prevents the dust which accompanies the gas from forcing its way down between the cylindrical slide-valve **s** and the valve-edge. The spring **u** brings back the valve to its seat again towards the end of the stroke.

The governing, in contrast with the older construction, is worked on the constant-quality principle, the amount of air and gas being simultaneously regulated by the greater or less lift of the inlet-valve. This alteration in the lift is obtained by altering the position of the block **x** on the rolling lever **r**. The shaft **v** standing in con-

nection with the governor, brings about this adjustment by actuating the links **w<sub>1</sub>**, **w<sub>2</sub>**, **w<sub>3</sub>**, and **w<sub>4</sub>**, which latter link moves the block **x**. The proportioning of the air and the gas is obtained by the adjustment by hand of the air-valve **s**, which is rotatable around the valve-stem. The air-valve is operated by means of the hand-wheel **y** (fig. 88).

#### Allis-Chalmers Co.

The engines (figs. 90 and 91) of this firm resemble in their chief features the Neurnberger engine of which they are really a development. Constant-quantity governing is employed. Both the inlet- and the exhaust-, and the gas-valves receive their movement through rolling levers from one and the same eccentric **a** (fig. 91). But above the inlet-valve disc **b** and centrally arranged around its stem there is arranged a double-ported poppet-valve, the gas-valve **c**, just mentioned, which standing under the influence of the governor regulates the amount of gas. This takes place in the following way: the said gas-valve is rigidly attached to a small cross-head **d**, which is pushed up and down by the action of the rolling levers **f** and **g**. The rolling lever **f** stands in connection with the eccentric rod **k**, by means of the rod **h**, while the lever **g**, which is forked around the cross-head guide and fulcrumed in the valve-hornet, is actuated by the governor by means of the eccentric rod **l** and the shaft **m**. The valve **c** can thus be made to keep open during a shorter or longer part of the suction stroke.

The air streams in under the gas-valve, and there mixes thoroughly with the gas, after which the charge rushes into the cylinder through the main inlet-valve **b**. The air is not at all acted on by the governor, for which reason an almost constant compression is obtained, independent of the load. The gas-valve is opened a little later than the main inlet-valve, and thus, at first, only air streams into the cylinder. The danger of back-fires (p. 282) is thereby diminished to the least possible. For the same reason, the gas-valve is also closed a little before the inlet-valve. The exhaust-valve and its seat are water-cooled.

The double-throw crank which is generally employed in European gas-engines has been omitted, and use has been made instead of the simple straight shaft, as employed in steam-engines, with shrunk-on loose cranks. In the case of such large powers as those now in question, the crank-shafts are of considerable dimensions, for which reason the forging is very difficult, and is made still more so by nickel-steel being the material employed. In addition to this, in the case of twin engines, with the fly-wheel and generators arranged between them, double-throw cranks will call for at least four main bearings lying in line, while for straight crank-shafts two bearings are sufficient. In consequence of this, the erecting in the latter case is considerably simpler, and the danger of heated bearings is less. These advantages must be purchased, however, at the cost of a con-

siderably larger shaft-diameter, and a considerably increased weight of the engine-frame. In order to relieve the frame as much as possible

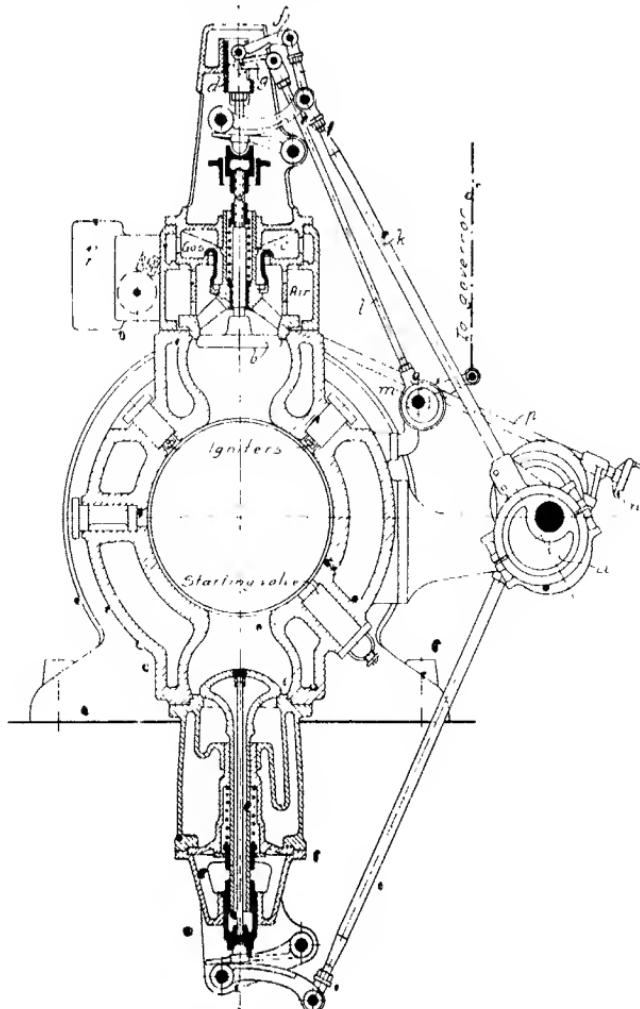


FIG. 90.

from extra bending stresses, and to transfer the bearing-forces directly instead, two tie bolts are arranged above the crank, connecting those parts of the frame that lie in front of, and behind the shaft.

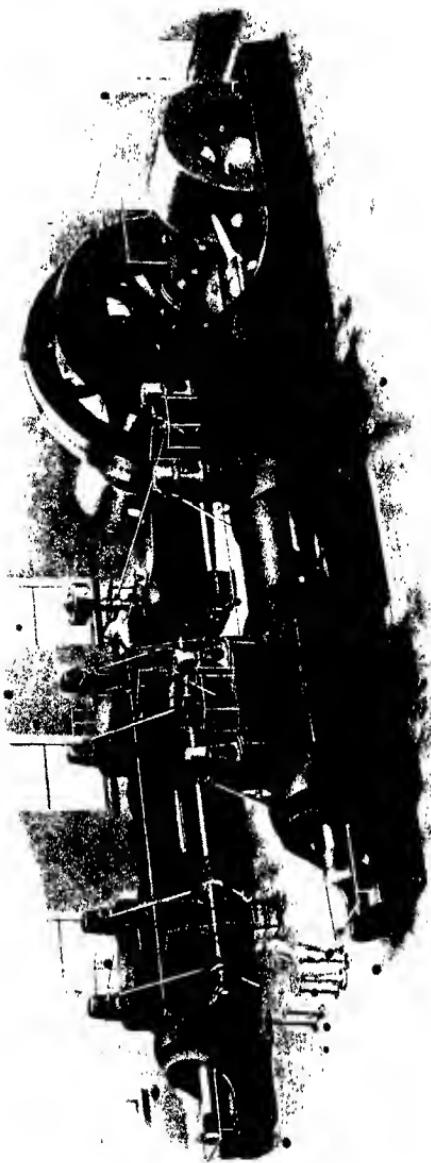


FIG. 91.—2500 K. W.

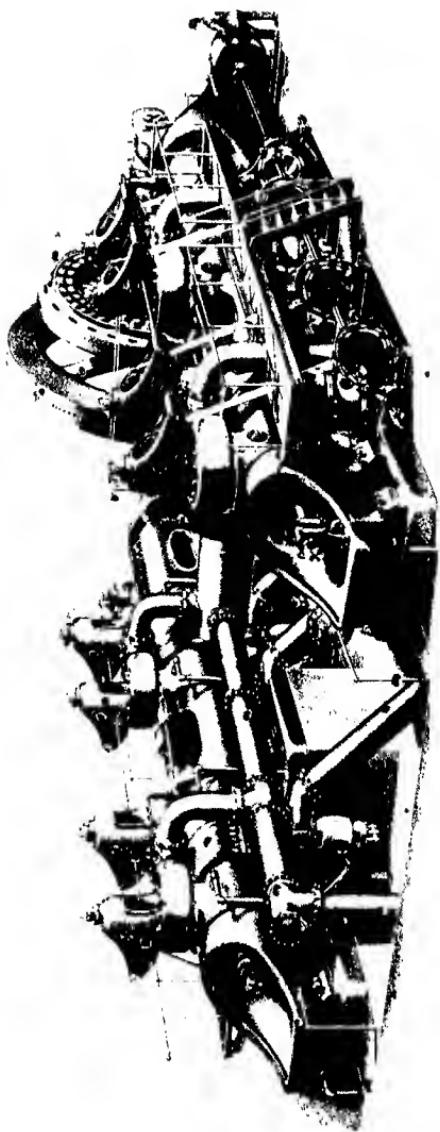


FIG. 92.

## The Westinghouse Machine Co.

Figs. 92-95 show a 3000-H.P. engine consisting of two twin engines, each composed of a double-acting tandem engine. In each cylinder there is thus developed 750 H.P. The engine presents several features worthy of attention. The cylinder is cast in two pieces (fig. 93), which, in the middle of the cylinder, are fastened together by means of shrunk-on I-links, while the jacket-wall is closed by means of a split band. The object of the division of the cylinder is to avoid cast- and heating-strains, and to reduce the weight of each special casting.

A single eccentric governs, by means of rolling levers, the inlet-valve as well as the exhaust-valve, the starting-valve, and the

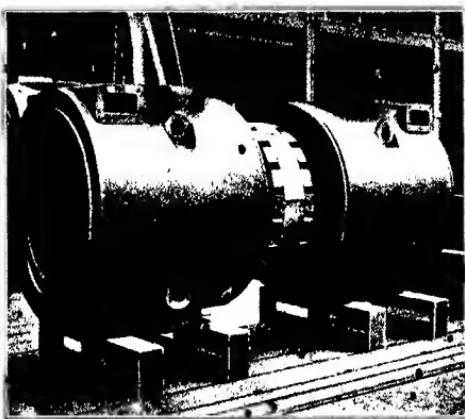


FIG. 93

ignition-gear. The regulating valves are made in the form of rotatable piston-valves and are connected with each other by means of reach rods. Such valves show, however, an inclination to stick, caused by the impurities in the gas, unless the regulating power of the governor is very great. For this reason, use has been made of indirect regulation in such a way that the governor does not act direct on the regulating valves, but only on a little balanced pilot-valve. This, in its turn, admits oil at 30 lbs. per square inch pressure to one side or the other of an hydraulic regulation-cylinder, while, finally, the piston of this acts on the regulating valves.

The ignition is effected by means of make-and-break igniters actuated by electro-magnets. Current is obtained from a little dynamo. Two igniters are used for each end of the cylinder, while in the case of large engines, three are employed.

A number of safety devices are employed. Should any fault

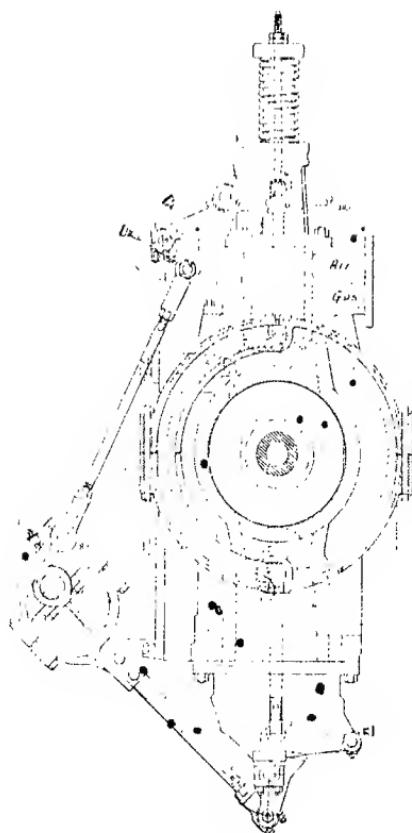


FIG. 94.

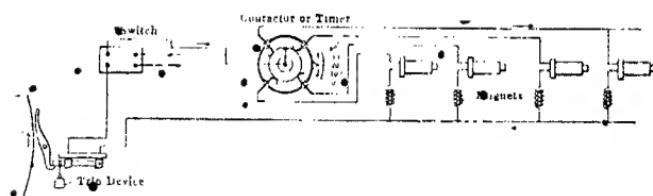


FIG. 95.

arise in the circulation of the cooling water, a switch inserted in the circuit of the igniting current is broken by a diaphragm. The engine then stops. In addition to this, it might happen that, for some reason

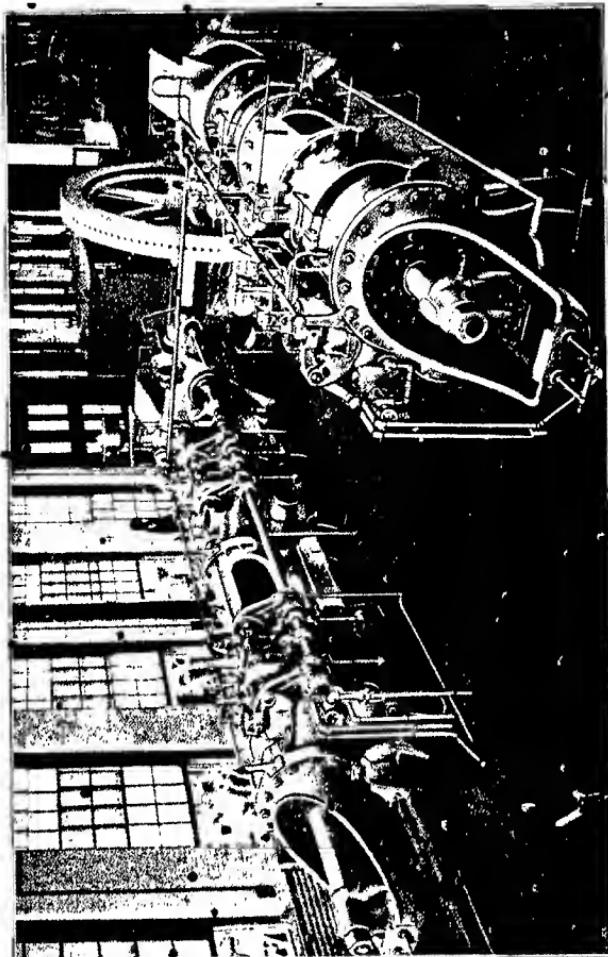


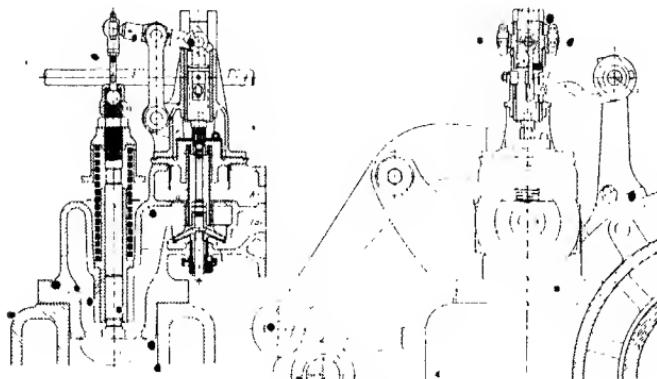
FIG. 96.

or other, the governor might be injured, and the load suddenly removed. In order, in such a case, to prevent the engine from racing, there is arranged in the fly-wheel a simple little governor in the form of a claw. Should a fixed number of revolutions be exceeded, the claw falls out and breaks the ignition (fig. 95).

## The Snow Steam Pump Works.

Fig. 96 shows an outside view of a twin tandem 850-H.P. producer-gas engine, and figs. 97 and 98 the arrangement of the inlet and the regulating valves. The engine differs from those hitherto described chiefly by the fact that the combustion-chambers are arranged on the side of the cylinder, carrying inlet-valves and gear on top, exhaust-valves and gear below (fig. 96). This construction makes it possible to keep the centre line of the engines down, and to keep all valve-gears above the floor. It also makes the foundation an unbroken block under the entire length of the engine.

The governor operates on the constant-quality principle, a release-gear being used for the regulation of gas and air. The main



FIGS. 97 and 98.

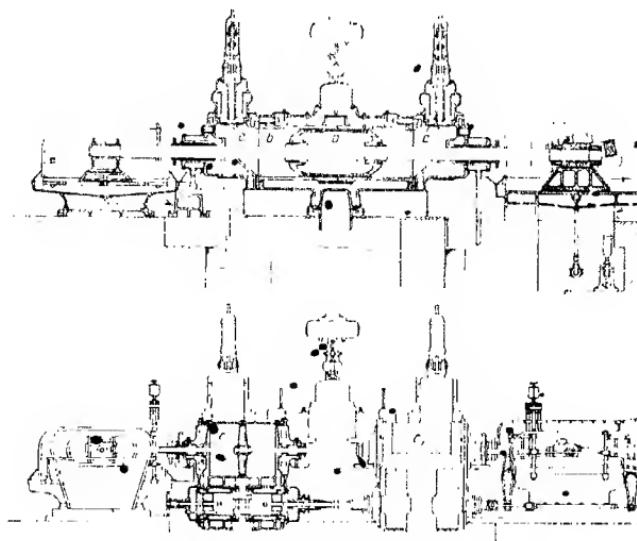
inlet-valve *i* (fig. 97) is actuated by a cam and a rocker, as shown in fig. 98. The air- and gas-regulating valve *a* is actuated in unison with the inlet-valve by means of the rocker *r* and the hook *l*. At a proper point of the stroke the link *h*, which is connected to *l*, will be pushed to the right by a cam *c* on the cut-off shaft *s*, which latter is driven from the cam-shaft by means of a hunting gear controlled by the governor. The regulating valve will then drop to its seat cushioned by the dash-pot *e*, thus cutting off the gas and air currents. The proportioning of the gas and air may be effected by means of the throttle-valve *b*, which can be adjusted by hand.

Like all large American gas-engines, an overhung crank-shaft is made use of, the Snow Company being, in fact, the first firm to depart, in this respect, from European practice. These engines have found their field largely in the natural gas- and oil-districts in driving gas-compressors.

## TWO-STROKE ENGINES.

## Gebruder Koerting.

Fig. 99<sup>1</sup> shows this engine in section through the working-cylinder; fig. 100 through the pumps; while fig. 101<sup>2</sup> is chiefly intended to illustrate the regulation. When the working-piston **a** has traversed about 85 per cent. of its working-stroke, it opens the ports **s** in the middle of the working-cylinder **b**, which lead to the exhaust-piping. The combustion gases, which are under high pressure, then stream out to the silencer at a great speed, 2500-3000 feet per second. Close by



FIGS. 99 and 100.

the working-cylinder, two pump-cylinders are arranged, **c** and **c<sub>1</sub>**, the pistons of which are driven by means of crank-motion from the engine-shaft, but from a crank which goes 110° in advance of the main engine-crank. The piston **c** sucks in gas, and the piston **c<sub>1</sub>**, air, and, during the charging period, they press the air and gas respectively into the working-cylinder. The pumps are regulated by means of piston-valves **k** and **l**, or **k<sub>1</sub>** and **l<sub>1</sub>**, respectively. Between them and the piping leading to the working-cylinder there are arranged non-return valves **m** and **m<sub>1</sub>**. During the latter part of the expansion stroke, the piston-valves **l** and **l<sub>1</sub>** take up such a position in respect to **k** and **k<sub>1</sub>** that the pistons in the pump-cylinders **c** and **c<sub>1</sub>** can push the gas

<sup>1</sup> *Stahl u. Eisen*, 1906.<sup>2</sup> *Z. Ver. deutsch. Ing.*, No. 7, 1908.

and the air before them through the respective piston-valves and back into that part of their respective cylinders which is on the opposite side of the pistons. In this process the non-return valves  $m$  and  $m_1$  prevent the gas and the air in the pipings from streaming back again. Then, when 30° remain to the end of the stroke (the figure shows this position), the inlet-valve  $e$  is opened at the same time that air and, afterwards, gas too, are conveyed thither from the pump-cylinders through the piping, which is marked by dotted lines. In order, as far as possible, to prevent the fresh charge from coming into contact with the hot gases in the working-cylinder (whereby ignition

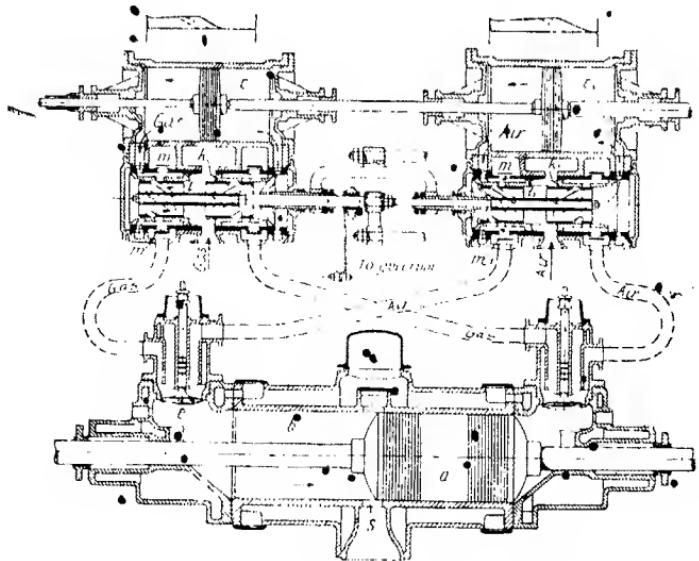


FIG. 101.

could easily occur), the piston-valves of the gas- and air-pumps are so regulated that air begins to be pumped into the piping, while the gas-piping is still kept closed. By this means a part of the air in the air-piping is pushed past the inlet-valve  $e$  and into the gas-piping, and the result of this is that, when the inlet-valve is first opened, only pure air at first comes into the cylinder, followed afterwards by the charge. It is also intended by this means to prevent the fresh charge from streaming out through the exhaust-ports. The mixture of air and gas which streams into the cylinder now pushes before it that part of the exhaust gases which has not already streamed out when the ports  $s$  were uncovered, and this results in the exhaust gases leaving the engine through the ports. The working-cylinder is thus freed from the combustion gases simultaneously with

a "charging" taking place, and this continues until the inlet-valve is closed at a  $60^{\circ}$  crank-angle on the other side of the dead centre. Just before this the exhaust-ports have been covered by the piston. The charge enclosed is then compressed to 140-170 lbs. per square inch pressure, and is ignited in the usual way in the neighbourhood of the dead centre, after which the piston turns, expansion begins, and the cycle begins once more. The piston-valves I and  $I_1$  are arranged as reciprocating rotatable valves with oblique ports, and are controlled by the governor. With light load the piston-valves I and  $I_1$  close the ports in the piston-valves k and  $k_1$  at a later crank-angle, thereby also delaying the admission of gas and air into the working-cylinder.

#### Oechelhauser's Gas-Engine.

It cannot be denied that this engine—the essential principles of which are shown by fig. 102<sup>1</sup>—is the finest of the two-stroke engines in respect to the logical consistency with which the essential principles

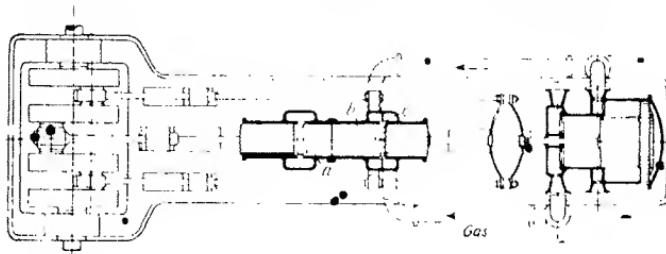


FIG. 102.

of the two-stroke engine have been carried out; and so a short description of it will probably be of interest, although this type of engine is now seldom built.

As is seen, the engine is provided with two pistons moving in opposite directions. The one is driven from the crank-shaft in the usual manner, while the other gets its motion by means of reciprocating rods driven by means of connecting rods from the same crank-shaft. When 23 per cent. of the expansion stroke still remains, the forward piston opens the exhaust-ports a which extend round the cylinder. Previous to this, however, air and gas have been pressed into reservoirs by special pumps, which, in the drawing, are placed right behind the working-cylinder. Then, when the pistons have come so far that only 11 per cent. of the piston-stroke remains, the rear piston opens a row of ports b arranged round about the cylinder. Through these the air rushes in from its reservoir and drives out the exhaust gases before it. Finally, when only 6 per cent. of the piston-

<sup>1</sup> Guldner, *Verbrennungsmotoren*.

stroke remains, the last-mentioned piston uncovers another circle of ports, *e*, through which gas alone enters. Then the pistons return, compress the newly introduced gas mixture, and so on.

By means of the construction with two pistons moving in opposite directions, a good many advantages are gained. First and foremost, an excellent combustion-chamber is obtained—a plain cylinder, which is exposed only to radially-acting gas pressure, but to no axially-acting forces at all, if we disregard the piston friction. But, above all, the air and the gas enter the cylinder quite *centrally* while the air that first enters forms an isolating layer between the hot exhaust gases and the combustible new charge. By this means the eddying movements are restricted in the greatest possible degree, thus avoiding the danger both of pre-ignitions and of the loss of gas through the exhaust. In addition to this, all valves in the working-cylinder are rendered unnecessary in this engine.

Compared with a four-stroke engine, however, this system offers scarcely any advantages. The engine does not become any simpler, for the valves which have been taken away from the working-cylinder have only been removed to the air- and gas-pumps—where, it is true, they are not exposed to high temperatures, however. Regarded as a whole, then, the engine is certainly not simpler than a four-stroke engine.

#### Some Points of Comparison between Four-Stroke and Two-Stroke Engines.

The fundamental idea of the two-stroke engine has been the following:—

With the four-stroke engine—and in this connection none but the ordinary single-acting four-stroke engines are considered—only every fourth stroke is a working-stroke, and, during both the first and the fourth strokes, the working-piston serves merely as a pump-piston. By arranging this pump-action in a special pump and letting the working-piston have only the compression and expansion strokes for its share (for which action it is better suited on account of its construction), the engine is so altered that, during a fixed number of revolutions, we obtain twice as many working-strokes. The engine thereby becomes twice as powerful, lighter, and cheaper in construction. We shall now examine some of the points of view to which attention should be paid in making a comparison between the different types of engines.

Each combustion-engine system stands or falls by the greater or less possibility it possesses of expelling the consumed gases from the cylinder and of introducing into the latter a sufficiently large new gas mixture, and of performing this in an effective, economical, and reliable manner.

In the case of the four-stroke engine we have two full strokes at our disposal. More than this, the driving out of the exhaust gases and the introduction of the new charge take place during

different periods, and do not synchronise with each other. Here we are quite sure that, under every circumstance, out of the cylinder can, first and foremost, be removed the whole of that amount of gas which corresponds to the difference in pressure at the close of the expansion- and during the exhaust-stroke. In addition to this, during the fourth stroke, the piston pushes before it (and out of the cylinder) a volume of gas which is about as large as the piston displacement. On the other hand, there will always remain a volume of burned, and thus inert, gases of the same volume as the compression-space. As this amounts, as a rule, to 20-35 per cent. of the piston displacement, it should be clear that, in the four-stroke engine, the purity of the charge is not always as perfect as it might be deemed at first sight. Now, if at the close of the exhaust stroke the pressure in the cylinder was, however, equal to that of the outer air, a four-stroke engine during the next stroke would be able to draw in a volume of charge equal to the piston displacement. This is far from being the case, however. At the close of the exhaust stroke there prevails, on the contrary, within the compression-space of the cylinder, a pressure which, as a rule, is greater than that of the outer air, and which may be very considerable, especially in the case of small high-speed engines. Then, when the piston turns and begins its suction stroke, the remaining gas must first expand down to the pressure in the inlet-piping before the piston can begin to draw in a new, fresh charge. Thus the volume of the new charge drawn in amounts to only a part of the piston displacement, and the volumetric efficiency (cf. p. 274) might fall very considerably under unfavourable conditions. An endeavour has been made to lessen this inconvenience by regulating the valves in such a way that the exhaust-valve is not closed until the suction stroke has begun, while the inlet-valve is opened at the end of exhaust stroke (cf. p. 120). But this can only improve matters in a certain degree.

In two-stroke engines things are still more unfavourable, however. When the piston has 20-25 per cent. of its stroke still left, the exhaust-ports are opened. During the short time the crank-pin now moves around the dead centre till the inlet-ports are again closed, so great a part of the consumed gases must first have time to stream out that the pressure sinks to nearly that of the atmosphere, and then a new charge must, in one way or another, be introduced, which has first to force out what remains from the previous combustion, and this without mixing with these remains. The greatest difficulty lies in the introduction of the charge without giving rise to eddying movements; for, if such movements arise, a part of the charge may easily be lost through the exhaust—which, of course, signifies a direct increase in the consumption of fuel per horse-power,—in addition to which the remaining part is greatly diluted by the inert gases, of which there remains a great quantity. This causes a deterioration of the combustion; the power of the engine sinks, and the consumption of fuel is increased still further. Moreover, the risk is run that in such a case

the new charge may be ignited by the remains of the old one, and this may bring the engine to a standstill. As was shown before, an endeavour has been made to diminish these inconveniences by introducing pure air as an isolating layer between the charge and the exhaust gases. The *Oerchhausen* gas-engine is, of course, somewhat better off in this respect than *Koerting's*, as, in the latter, air and gas are introduced through valves which cannot be placed centrally in the cylinder-head: but, in any case, the whole of this method of charging is a very delicate one.

When valves are employed for the introduction of the charge, they must be given pretty large dimensions, because the time they can be kept open is so short. But as the cam-shaft of a two-stroke engine must rotate with the same number of revolutions as the main shaft, the difficulties of so controlling the inertia-forces that impacts shall not arise in the valve-gear are greater than in four-stroke engines of a corresponding size. These difficulties can be mastered, however, by keeping the masses which are to be accelerated as small as possible, by a suitable design of the valve-gear, and by lowering the acceleration itself to the least possible amount—the latter standing in direct connection with the lift of the valve. As a consequence of this, the designer must eventually allow a larger charging-period.

For these reasons the number of revolutions, in the case of great power, cannot be brought to the same height with a two-stroke engine as with a four-stroke one. Thus, for example, a 1000-H.P. two-stroke engine can scarcely be run with more than 75-85 revolutions per minute, while, on the other hand, a four-stroke engine of the same power can very well run with 110 revolutions per minute. We find, therefore, that the two-stroke engines have a longer stroke. For economical operation, however, a high number of revolutions is of great importance, as the cost-price is nearly always lower the greater the number of the revolutions. Thus, for example, if a gas-engine is to run an electric generator, the expense of the electric parts is considerably lower with a high number of revolutions. It is, of course, the total cost of the installation that determines the matter, and so, in certain cases, a two-stroke engine may be preferable if the price is lower. And in many instances a high number of revolutions would not, in any case be employed for other reasons. Such instances are the driving of large pumps, blowing-engines, etc. The space necessary for a two-stroke gas-engine is less, too.

As we see by fig. 101, the working-piston must be made fairly long, as, during the greater part of the stroke, it has to keep the exhaust-ports covered. In the case of such large engines as those now in question, the danger of wear and tear of the piston and cylinder, caused by uneven expansion, naturally increases. On account of the great length of the piston in two-cycle engines, it cannot be floated on its rod, but is, instead, carried by the cylinder. It need not be said that the impurities which (in spite of extensive cleaning apparatus)

always exist in the gas can cause far more damage when they get in between the cylinder-wall and the piston, which lies against it with all its weight, than in an engine where the piston has considerable clearance, and where only the piston-rings exert a light pressure on the cylinder-wall. On the other hand, this inconvenience of the two-cycle engine must not be exaggerated, as the wear of the cylinder is much more to be ascribed to the action of the piston-rings with their sharp edges than to the pressure of the piston itself, a fact that can easily be observed in any engine with an open-end piston which has been running some length of time. On the whole, many engineers consider well-designed and well-built four-cycle engines to be more reliable in operation, and to cause fewer interruptions, than corresponding two-cycle engines. It should be remarked, however, that many four-cycle engines have been built by very large and well-known firms which have not fulfilled reasonable expectations, so that other engineers entertain opposite opinions to those just quoted.

A general opinion as to the superiority of four- or two-cycle engines cannot be given, as the points of view that are decisive of this question are most intimately connected with the design of the engine and with its use.

With such oil-engines where pure air streams into the cylinder and drives out the exhaust gases, and where the oil is injected afterwards, other points of view should also be taken into consideration. There is here no danger at all of ignitions caused by the hot exhaust gases during the charging period. On the other hand, many of these engines are not provided with a special air-pump, but the crank-case has to serve for this purpose. The consumed gases leave the cylinder through ports on one side, while the air enters through ports on the opposite side. The introduction of air without eddying movements thereby becomes impossible; neither can a sufficient amount of air be got to stream in. Many such engines suffer from a considerably decreased power as soon as the crank-shaft bearings become worn, for then the air leaks out on the downward movement of the piston. This can be prevented, however. With many, but not all, of these engines, it has proved that the piston and the cylinder get worn out pretty quickly. This results, of course, in increased leakage from the cylinder past the piston and down to the crank-case, thereby lowering the power still more. An advantage of very great weight in the case of two-stroke engines often is, however, that, on account of their simple construction, they can be purchased cheaply.

In the case of a number of two-cycle engines—small petrol-engines, for instance—the charge is drawn in ready-mixed into the crank-case. Then, when the charge streams into the cylinder it happens, especially when the number of revolutions is low, that it is ignited by the hot gases, causing the explosion to blow back into the crank-case. In order, in such a case, to be able to keep the engine running until

a new charge can be introduced into the cylinder, a relatively heavy fly-wheel is required. We find, therefore, that such two-cycle engines are often provided with heavier fly-wheels than four-cycle engines of corresponding size.

In the case of two-stroke engines with special pumps, these latter often require great power, on account of resistance in the valves and piping. The charging-work with two-cycle engines has here been measured up to 20 per cent, and more of the indicated total work, while in the case of four-cycle engines it amounts to 4-5 per cent. Lately, however, the loss has been reduced to 7-13 per cent. in the case of the first-named engines. In reality, it has proved that a two-stroke engine does not by far give twice the power of a four-cycle engine, of the same cylinder-dimensions and number of revolutions. In favourable cases it may give 60-90 per cent. greater power; but, as regards small engines, the increase is very often little or none. From what has been said above, it follows that, as regards the consumption of fuel, the four-cycle engines, as a rule, have a little advantage over two-stroke engines.

#### Suction-Gas Engines for Ships.

After such brilliant results had been obtained in the case of stationary installations with combustion engines as compared with steam-engines, the idea naturally presented itself of endeavouring to make use of the experience gained for ships. A diminished demand for space could there be expected, not only for the engine and producer as compared with the steam-engine and its boiler, but for the fuel likewise. It should be possible, too, to reduce the consumption of fuel to about half of what it is at present. For carrying-ships this would mean increased capacity of carriage and cheaper working expenses, and for ships-of-war, increased range of action. A good steam-engine installation on a warship consumes 2-2.4 lbs. of coal per B.H.P. per hour, while a gas-engine gives the same power with 0.9-1.1 lb. In other words, by employing gas-engines the range of action could be increased by 2-2½ times. This is on the supposition, of course, that it is not possible to further reduce the consumption of coal in the case of steam-engines from what it is at present. There is, however, a possibility of doing this by employing super-heated steam.

As regards *weight* this is at present with steam per B.H.P.:-

TABLE XIV.

|  | Engine. <sup>1</sup><br>lbs. | Boiler. <sup>2</sup><br>lbs. | Piping, <sup>3</sup><br>etc.<br>lbs. | Total<br>weight.<br>lbs. |
|--|------------------------------|------------------------------|--------------------------------------|--------------------------|
| For carrying-ships . . . .                                   | 140-230                      | 185-220                      | 88-120                               | 430-575                  |
| „ <i>swift</i> passenger steamers .                          | 120-175                      | 130-185                      | 55-77                                | 310-440                  |
| „ ironclads ( <i>forced steaming</i> ) .                     | 70-88                        | 92-120                       | 35-48                                | 260-260                  |
| „ light cruisers ( <i>forced steaming</i> ) .                | 48-73                        | 48-110                       | 24-38                                | 120-220                  |
| „ torpedo-boats and<br>destroyers ( <i>forced steaming</i> ) | 20-35                        | 24-38                        | 10-20                                | 54-93                    |

It ought to be possible to produce a gas-engine installation of the same or less weight. The substitution of producers for boilers would also render a smaller number of stokers necessary, and their work would become less oppressive, as the radiation of heat from producers cannot be at all compared with that from steam-boilers. If we add to this the fact that, in the case of suction-gas machinery, there would be no necessity for piping under pressure, this, too, should contribute to a simplified operation.

The advantages for warships would be still greater, as funnels would become unnecessary. In the case of large ships this means increased shooting capacity, and, for torpedo-boats increased safety in manoeuvring and fighting value, as their position and movements would not be betrayed by the light and smoke above the funnels.

These points of view make the problem a very attractive one, but, unfortunately, there are great difficulties in the way of its solution. Although early experiments on a small scale have been made with suction-gas machinery for vessels, it is the German engineer *Capitaine* who has the credit of having brought the matter forward, and of having shown its practicability. *Capitaine* himself, however, has only built smaller plants for canal trading-ships and similar vessels, where the greatest difficulties could scarcely be expected to appear. It is England which, assisted by *Capitaine*'s patent, has seriously attempted the solution of the problem, and several firms in that country are at present working very energetically in this matter.

In stationary plants the engine, as a rule, works under a load which does not vary so very greatly, and, in any case, the changes in load do not follow so suddenly on each other as they do in the case of marine engines. It is true that, nowadays, the engine can easily follow these variations; but this is not the case with the producer,

<sup>1</sup> By *engine* is understood main engine with shaft and propeller.

<sup>2</sup> By *boiler* is understood boiler (empty) with all fittings and smokestacks.

<sup>3</sup> By *piping, etc.*, is understood piping, pumps, grating, ladders, etc.

which, in its entire character and method of working, is more suited for continuous operation. It is probable that this difficulty will be got over by keeping the producer in continuous working by means of auxiliary machinery, which will be independent of the speed and load of the engine at any given moment.

Evidently, the problem cannot be considered as perfectly solved. It is scarcely possible to drive large ships with anthracite and coke, and, at the present price of anthracite, would hardly pay. Neither can such gas-producing methods, the economical results of which depend on a utilisation on a large scale of the by-products, be employed. Shipping companies will most certainly not remove steam-engines and boilers from their ships in order to install chemical works on board.

Capitaine himself does not seem to have anticipated any great difficulties with respect to the producer; but he considered it necessary, on the other hand, altogether to condemn all existing types of engines as useless when a great amount of power is needed. He supported his opinions by certain considerations concerning the weight of the engines, etc., which we need not enter into here, but which seem to rest on somewhat superficial bases, for a suction-gas engine for marine purposes can certainly be built in accordance with either the four-cycle or the two-cycle system.

On the other hand, it is an imperative necessity for the engines to be made reversing, for reversing-gears and adjustable propeller blades can hardly be employed with engines of more than 100 H.P. The reversible suction-gas engines hitherto constructed have been provided with a hydraulic coupling between the crank- and the propeller-shaft. By this means, the propeller can be disconnected from the engine, during the short space of time required for the reversing of the engine, by means of compressed air. This system, however, can hardly be considered as acceptable in the case of large powers. In such cases rigid coupling will be an indispensable condition.

Another matter that has to be taken into consideration is that the resistance of the ship is diminished very quickly with decrease of speed. The engine must, therefore, be able to work both with a low number of revolutions and with a considerably reduced mean pressure (cf. p. 272), and this must be obtained without the use of large and heavy fly-wheels. Now, it is fortunately the case that the dimensions of the fly-wheel diminish very rapidly in proportion as the number of cylinders increases. A moderately high number of cylinders is desirable, however, in order to get good power of reversing, capability of manoeuvring, and reliability. With a large number of cylinders, it is possible for one of them to be closed at a time for the cleaning of the valves, the inspection of the igniters, etc., without the engine having to be stopped for this purpose. The calculations respecting this matter which the writer has carried out showed that, with 71 lbs. compression- and 355 lbs. explosion-pressure--and under the supposition that there is constant degree of irregularity, in horse-

power, diameter of fly-wheel, and number of revolutions—the necessary fly-wheel weights in the case of 8-, 6-, and 4-cylinder four-stroke engines, stand in the proportion of 1 : 3.5 : 9. These figures show in what a high degree the weight of the fly-wheel is dependent on the number of cylinders. This, however, is counterbalanced by the fact that larger engines must work with a lower number of revolutions.

Capitaine considered that it was not possible to build sufficiently light engines with present designs. He therefore constructed both the frame and the bed, and even the cooling jacket-wall, of steel-plate and angle-iron (fig. 103).

This peculiar construction has been hailed in the technical press of the world as a very great step forward, by means of which the weight of the engine could be considerably reduced. The inventor himself states that the gain amounts to 10-15 per cent. Fig. 133 shows, however, that it is possible to reduce the weight in a still higher degree by other means. It has also been advanced in favour of the construction in question that the engine-frame can be riveted fast direct to the stringers of the ship, and thus help to stiffen the ship itself. The question then naturally presents itself, whether it really is of advantage to make use of this fact. Such a stiffening

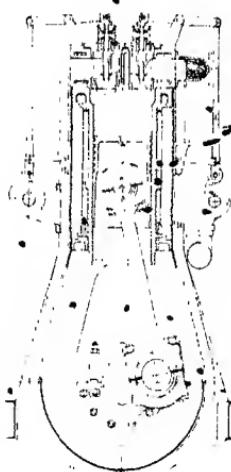


FIG. 103.

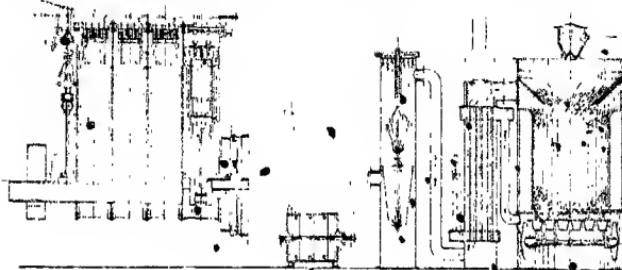


FIG. 104.

must very naturally stand in connection with alterations in form, and it seems as if it might too easily happen that a crank-shaft bearing would get heated in a rough sea just when engine-power is most needed.

Fig. 104 shows diagrammatically the general arrangement of a

Capitaine suction-gas engine. From the producer, which is provided with movable grate, the gas passes through an ordinary vaporiser, and from there to a scrubber into which the water is injected like a fine rain, which cools the gas and binds the accompanying dust.

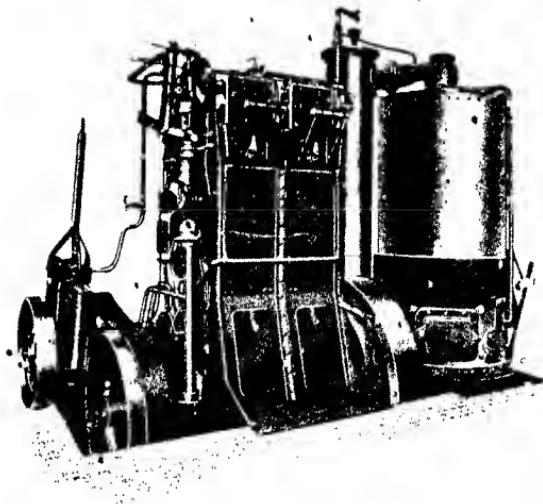


FIG. 105.

From the scrubber it passes through a rapidly rotating centrifugal cleaner and, finally, to the engine.

Fig. 105 shows an exterior view of the machinery as it appears in reality. Some years ago a 5-cylinder 500-H.P. engine was installed in an English training-ship for experimental purposes. The engine in question was started by means of the ignition of a gas mixture enclosed in the cylinder.

## CHAPTER III.

### OIL-ENGINES.

THE great advantages offered by combustion engines become, in some cases, still more apparent when liquid fuel is used instead of solid. This is especially the case with smaller engines, and with such as are used very irregularly, and, above all, those which are not stationary. Oil is simpler and cleaner to handle than coal, and there is no need for producers with scrubbers. This simplifies the attendance, and much space is often gained. On the other hand, oil-engines, as a rule, present greater difficulties in respect to good combustion and colourless exhaust gases than gas-engines, as soon as it is a question of employing cheap, or relatively cheap, oils.

In the case of oil-engines the producer of the gas-engine must, of course, be replaced by something else, but it cannot be entirely dispensed with. The finely dividing and the mixing of the fuel with the combustion air takes place, for the most part, in *carburetters*, or *vaporisers*, as well as by the help of compressed air, while its introduction into the cylinder along with air takes place by the suction of the engine-piston, or else the fuel is pressed direct into the engine, and is finely divided by the help of *oil-pumps* or *compressed air*.

#### I. ACCESSORIES.

##### *Carburetters.*

With engines operating on oils that can be vaporised comparatively easily, such as petrol, alcohol, and benzol, an attempt is generally made to divide the liquid finely or to vaporise it entirely. The liquid, or the vapour, is then mixed as well as possible with the combustion air. The apparatus which is employed for the production of combustible gas mixtures is called a carburetter. A distinction is made between *surface-carburetters* and *spray carburetters*.

With the former the air is conducted through the fuel, or use is made of wicks, or the like, in order to render a good vaporising possible, and, at the same time, to saturate the air with the vaporised fuel. The apparatus, which is based on vaporising pure and simple, is being less and less used, although every now and then some new

design is introduced into the market with a great flourish of trumpets, the last occasion lying in connection with benzol. Their greatest fault is that only the easily vaporisable substances in the fuel are carried off by the air, while the heavier remain. This is the case with petrol, even, which, in other respects, is an ideal fuel. They also increase the suction resistance of the engine in a high degree, the result of which is that a less amount of the gas mixture is sucked in, and that the power of the engine is thus diminished. Finally, their power of regulation is very poor, and their weight and volume are often pretty considerable.

With *spray carburetters* on the other hand, the fuel is introduced through a fine nozzle into the air, where it is afterwards finely divided and mixed. A vapourisation of the lighter substances only is, therefore, prevented.

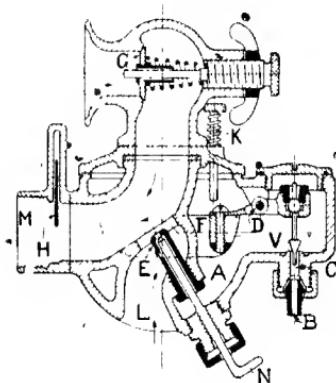


FIG. 106.

Fig. 106 shows a *Schebler* carburetor somewhat altered. The chamber **A** is kept filled with petrol, which enters at **B** and passes the hole **C**. The level of the liquid is regulated by the float **F** and the valve **V**. This takes place as follows: The float **F** is made of cork covered with shellac. It can thus float in the petrol. The float is pivoted around the pin **D**, and at its other end carries the needle-valve **V**. When the level of the petrol sinks, the float sinks with it, and thus lifts the valve. The petrol then streams in from the tank which lies above it; but, with a rising level of the petrol, the float, too, rises, until the needle-valve **V** strikes against its seat. The admission of petrol is thereby cut off. In a short time the level of the petrol has sunk so much that the float once more moves downwards. The valve is then opened, the petrol streams in again, and the float rises, etc. As, by means of this construction, a very sensitive float and valve apparatus can be obtained, the petrol can be kept at practically a constant level. At the orifice **M** begins the inlet-pipe of the engine. During the suction stroke a vacuum arises, in which process the air streams in through the inlet **L** and rushes with great speed past the petrol nozzle **E**. The vacuum at this point usually amounts to 12-16 inches water-column. On account of the difference in pressure to which the petrol is thus exposed, the petrol spurts out through the nozzle **E** and is carried along by the air which rushes in through **L**. This air, on its way to **M**, is suddenly compelled to alter its direction, thereby contributing to a better mixing of the petrol with the air. On its way to the engine through the carburetor

## INDEX.

ABEL's test, 60.  
 Adiabatic expansion, 218.  
 Air-cooling, 249.  
     -gas, 8, 12.  
     required for combustion, 277.  
     starting, 143.  
 Alcohol, 63.  
 Allis-Chalmers engine, 183.  
 Anthracite, 5, 21.  
 Anzinetto motor, 226.  
 Arc-light ignition, 140.  
 Ash-pit, 8, 66.  
 Augsburg-Nürnberg engine, 167, 179.  
 Automatic scavenging, 115.  
     valves, 118.  
 Automobile motors, 243.  
 Avance motor, 215.  
  
 BACK-fires, 282.  
 Barometric pressure at different altitudes, 279.  
 Battery-and-cord ignition, 128.  
 Bearings, 113.  
 Beau de Rochas, 103.  
 Benzine, 5, 61.  
 Benzol, 64, 200.  
 Bian washer, 49.  
 Blast-furnace gas, 40.  
     analysis of, 41, 42, 43.  
     cleaning apparatus, 47.  
     combustion-air required, 43, 277.  
     heating value of, 42, 277.  
 Boulton motor, 228.  
 Borneo oil, 63.  
 Bosch ignition, 138, 139.  
 Boudouard's experiments, 9.  
 Brake horse-power, 272.  
 Brayton engine, 108, 121.  
 Burning-point, 60.  
  
 CALORIMETER, Junker's, 280.  
 Cams, angles of, 120.  
 Carburetted water-gas, 7.  
 Carburetters, 203.  
 Catalysis, ignition by, 121.  
 Charging apparatus, 8, 69.  
     valve, 69.  
  
 Cleaning and drying apparatus for  
     producer-gas, 76.  
     for blast-furnace gas, 47.  
 Cochin-Ehrenfeld engine, 168.  
 Coke, 5, 22.  
     oven gas, 56, 277.  
 Combustion, 261.  
     air required for, 277.  
     zone, 9.  
 Comparison between four-stroke and  
     two-stroke engines, 194.  
 Compression-pressure, 262.  
 Connecting rods, 117.  
 Constant-pressure engines, 108.  
 Cooling, 146.  
     water required, 148.  
     utilisation of the heat of, 150.  
 Corrosion, due to sulphur in gas, 112,  
     151.  
 Cost of fuels, 5.  
 Crank-shaft, 117, 183.  
 Crossley engine, 119, 139.  
 Crude oil, 61.  
 Cycles, 103.  
 Cylinder, 113.  
     dimensions, calculation of, 270.  
     -head, 114.  
  
 DAIMLER automobile motor, 245.  
 Denatured alcohol, 63.  
 Depreciation, 284.  
 Daimler engine, 110, 165.  
     ignite producer, 97.  
 Diesel engine, 108, 218, 238.  
 Disassociation, 263.  
 Disturbances in the working, 280.  
 Dixon's experiments on explosion, 267.  
 Down-draught producers, 27.  
 Dowson gas plant, 17, 86.  
 Drain box, 77.  
 Dry batteries, 27.  
     distillation, 9.  
     scrubber, 78.  
 Dual ignition systems, 141.  
 Dust, amount of, 45.  
  
 ECONOMY of combustion engines, 283.

Effective heating value, 4, 277.  
 horse-power, 272.  
 Efficiency, mechanical, 272.  
 thermal, 272.  
 volumetric, 274.

Electrical ignition systems, 126.

Engine-bed, 113.  
 -power at different altitudes, 273.  
 E.L.C. Milt-Peltier motor, 253.

Ethylene, 25.

Exhaust-piping, 151.

Explosion engines, 103.  
 pressures, 262.  
 waves, 267.

FIRE-WATER regulator, 73, 91.

Filter, 78.

Flame-propagation, 268.

Flashing-point, 60.

Flying-machine motors, 252.

Foundations, 159.

Four-stroke cycle, 103.  
 engines, 165, 175.

Franklin motor, 249.

Fuel economics, 4.  
 -hopper, 19, 69.  
 -magazine, or container, 19, 70.

Furnace shaft, 8, 66.

**G**AS, blast-furnace, 40.  
 carburetted water, 7.  
 coke-oven, 56.  
 engine cycles, 103.  
 engines, 109, 165, 274.  
 illuminating, 56.  
 meter, 155.  
 natural, 40.  
 pressure regulator, 4, 4.  
 producer, 7.  
 Siemens', 8, 12.  
 tank, 79.

Gasification, 9.

Gasoline, 5, 61.

Gantzi, 151.

Gasoline motor, 855.

Governing by retarding the ignition, 161.

Combination systems, 164.  
 constant-quality, 164.  
 -quantity, 162.  
 hit-or-miss, 161.  
 systems of, 159.

Grate-area, 67.

HEAT-BALANCE, 263.  
 price, 4, 5.  
 unit, 271.

Heating value, 4, 277.

Holmberg gas-producer, 91.

Hondol ignition, 139.

Horch motor, 245.

Hornsby engine, 115, 214.

Horse-power, 271.

Hot-bulb ignition, 122.  
 -tube ignition, 121.

Humphrey gas-jump, 257.

Hydrocarbon loss in tar, 14, 25.

**I**GNITER, 132.

Ignition systems, 121.  
 arc-light, 140.  
 battery-and-coil, 128.  
 by catalysis, 121.  
 by external flame, 121.  
 by hot bulb, 122.  
 -tube, 121.  
 by external flame, 121.  
 by means of electrically heated metal, 126.  
 electrical, 126.

Lodge, 133.

make-and-break, 131, 135.

Illuminating gas, 6.

Indicated horse-power, 272.

Indicator card, 104.

Induction coils, 129.

Injection of water in the cylinder, 1, 235.  
 in the exhaust-pipe, 154.

Inlet-piping, 150.

Installations, 288.

Isothermal expansion, 218.

**J**UMP-SPARK ignition, 132.

Junker calorimeter, 280.

**K**EROSENE, 62, 277.

Knight sleeve-valve motor, 245.

Koerting four-cycle engine, 172.  
 two-cycle engine, 191.

peat-producer, 25, 33.

**L**ENOIR engine, 103.

Lignite, 39.

Liquid fuels, 5, 57.

Lodge ignition, 133.

Longueville carburettor, 206.

Losses in engines, 270.

Distributing oil, amount of, 258.

Lubrication, 155.

**M**AGNETO-ELECTRIC ignition, 135.

Make-and-break ignition, 131, 135.

Mallard and Le Chatelier, 267.

Mean pressures, 270, 274, 277.

Measures of precaution, 283.

Mechanical efficiency, 272.  
 equivalent of heat, 271.

Methane, 25.

Methylated spirit, 63.  
 Mond gas, 30.  
 Motor-car engines, 243.

**N**ATURAL gas, 40.  
 Nordiska Motorverkstäderna, motor, 216, 236.  
 Nydqvist & Holm producer, 91.  
 engine, 113, 171.

OECHELHAUSEN's gas engine, 193.  
 Oil, amount of, 458.  
 engines, 203, 213, 275.  
 pumps, 211.  
 Oils, 5, 67.  
 Otto cycle, 103.

**P**ARAFFIN, 62, 61.  
 Parson's engine, 213.  
 Peat, 34.  
 briquettes, 38.  
 producers, 21, 33, 41.  
 Petrol, 5, 61.  
 Petroleum, 1.  
 Piping, 150.  
 of a suction-gas plant, 79.

Piston, 116.  
 cooling, 149.  
 displacement, 103.  
 pin, 116.  
 rings, 116.  
 rod, 176.  
 speed, 273.  
 stuffing-boxes, 177.

Power, 271.  
 at high altitudes, 279.  
 cycles, 203.  
 plants, 288.  
 operating cost of, 285.  
 Pre-ignition, 282.  
 reversing by means of, 222.

Pressure, compression, 262.  
 explosion, 262.  
 mean effective, 274, 277.  
 indicated, 273, 274.

Producer, double-zone, 28.  
 down-draught, 27.

Producer-gas, 7.  
 peat, 24, 33, 93.  
 Producers, different types of, 86.

Proportions of fuel and air, 277.

**R**EDUCTION-FACTORS, 299.  
 furnaces, 26.  
 zone, 9.

Reversible engines, 222, 230.  
 by compressed air, 230.  
 by premature ignition, 222.  
 Riché producer, 27.

**S**CAVENGING, 24.  
 Scrubber, dry, 78.  
 Scrubbers, 48, 77.  
 Self-ignition, 282.  
 Sewer-gas, 7, 11.  
 Siamese, 150, 152, 153.  
 Simms ignition, 140.  
 Six-stroke cycle, 107.  
 Slow combustion, 267.  
 Snow engine, 191.  
 Solar oil, 63.  
 Specific gravity, 60.  
 heat of gases, 16.  
 Speed, mean piston, 273.  
 Standard engine, 231.  
 Starting arrangements, 142.  
 Stradie's experiments, 10.  
 Stuffing-boxes, 177.  
 Suction-gas engines for ships, 198.  
 plants, 17, 86.  
 Svea motor, 216.  
 Swedish shale-oil, 65.

**T**AR-PRODUCTS, their decomposition, 24.  
 Texas oil, 63.  
 Theisen washer, 51.  
 Thermal efficiency, 272.  
 unit, 271.  
 Thornycroft engine, 232.  
 Two-stroke cycle, 106.  
 engines, 191.

**U**NITS, 271.

**V**ALVE cams, 120.  
 port area, 120.  
 Valves, 117.

Vapourisers, 70, 209.

Velocity of flame propagation, 268.

Viscosity, 60.

WASTE gases, utilisation of the heat of, 152.  
 Water-cooling, 146.  
 -gas, 7.  
 carburetted, 7.  
 -seal, 77.

Westinghouse engine, 187.



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